THE RELATIVE INFLUENCE OF RAINFALL, TOPOGRAPHICAL POSITION AND DISTANCE FROM VILLAGE ON COMPOSITION AND STRUCTURE OF HERBACEOUS VEGETATION IN A COMMUNAL RANGELAND OF BUSHBUCKRIDGE

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(Coursework and Research Report)

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DECLARATION

I declare that this research report is my own, unaided work except where otherwise acknowledged. It is being submitted for the Degree of Master of Science in Environmental Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

12th day of September, 2017 in Johannesburg

ABSTRACT

Various studies have been conducted on the determinants of herbaceous vegetation composition and structure in savannas, but there is still no consensus on the extent of the role played by each. This is particularly so for disturbed savannas in communal rangelands. This study aimed to investigate the relative influence of rainfall, catenal position and distance from village on composition and structure of herbaceous vegetation in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. The study used pre-existing data collected in 2012 in 56 plots located across nine villages in three rainfall zones: Low (<600 mm), Medium (600-700 mm) and High (>700 mm). In each zone, the communal rangelands of three villages were sampled in upslope and downslope positions and across three distance (disturbance) categories of, 0-599 m, 600-1799 m and >1800 m relative to nearest villages. The composition-related measures investigated were: absolute and relative abundance of species present, species richness, Simpson's Diversity Index and relative abundance of perennial and annual grasses, as well as categories of forbs whilst the herbaceous structure measures used were distance in meters measured along transect line to perennial grass tuft and grass basal cover. Both individual and interactive effects of the rainfall zone, landscape position, and distance from village on herbaceous composition and structure were investigated using bivariate and multivariate statistics.

Both grass species richness and Simpson's Diversity Index were significantly higher in the high rainfall zone than in the low and medium rainfall zones. Perennial grasses in all rainfall zones heavily dominated the herbaceous layer, with the mean percentage perennial grass contribution being lowest in the high rainfall zone whilst the low rainfall zone had the highest. The percentage composition of annual grasses was highest in the medium rainfall zone and lowest in the low rainfall zone whilst it was intermediate in the high rainfall zone. The mean distance to perennial grass, which is an index of density of perennial grass tufts, was significantly higher in the high rainfall zone than in the low rainfall zones. The mean percentage grass basal cover was higher in low rainfall zone than in high rainfall zone.

The mean species richness in the upslope and downslope catenal positions was not significantly different which was contrary to what was expected. Mean Simpson's Diversity Index was higher on the downslope position than on the upslope catenal position. The relative abundance of perennial grasses between the upslope and downslope catenal position was not significantly different. The proportion of perennial grasses was more than that of annual grasses and other life forms sampled.

Neither mean distance to perennial grass nor basal cover differed significantly between catenal positions. It was established in this study that closest plots to villages had 22% more species than the plots between medium and far plots from the villages. Near the villages (0-599 m), the species richness was found to be higher than in the medium (600-1799 m) and (>1800 m) distance categories. The mean Simpson‘s Diversity Index in all distance (disturbance) categories were found to be not significantly different. There was no significant difference in the percentage of perennial grass among the disturbance gradient categories. The perennial grasses were consistently dominant over the annual grasses along the disturbance gradients. The distance to perennial grass indicated no difference across all distance gradients. Percentage basal cover decreased with increasing distance from settlements.

The composition and occurrence of grass species were associated with different environmental gradients studied. There was significant interactive effect due to a combination effect of rainfall, topographical gradients and distance gradient on the distance to perennial grass. However, the mean distance to perennial was lower at distance and rainfall combination, though was not significant. The interactive effect on basal cover due to a combination effect of rainfall, catenal position and distance gradient was found to be not significant.

Overall, the herbaceous composition and structure was more strongly impacted by rainfall zone than by catenal position. The herbaceous composition and structure was affected by disturbance gradient specifically on species richness and grass basal cover only, while there was no effect on Simpson’s Diversity Index, perennial grass percentage, and distance to perennial grass as measured along transect line. It was also established that there was association of species with environmental gradients. It is recommended that in future a multi-year study on the same variables that have been studied here be undertaken in order to establish long-term trends on the effect of the gradients on herbaceous vegetation. It must be ensured also that there be representativity of disturbance gradients samples when designing sampling programme. It will also be beneficial to establish the density per village or stocking rates of different villages and the management aspects of the stock and how it is related to herbaceous composition and structure. Such studies will provide further knowledge on the extent of human induced disturbance like grazing in the communal rangelands given a set of environment gradients.

DEDICATION

I wish to first dedicate this work to the Almighty God for making possible for me to complete this work. Secondly to my mother and wife, Maletjema and Mabu, respectively.

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Savannas are said to be a tropical and seasonal ecosystem containing a discontinuous layer of trees and continuous layer of herbaceous plants including grasses, forbs and sedges, occurring in different ratios (Khavhagali & Bond, 2008). Due to the interaction that the trees and the herbaceous layer have to create a biome, savannas cannot be defined as grassland or forest (Scholes & Archer, 1997). They occur in regions that are associated with climate and precipitation that is spatially and temporally variable (Jeltsch *et al.*, 1997). More than half of the African continent is comprised of the savannas which support a great percentage of its people and animals (domestic and wild), with the rangelands in particular having the greatest density and diversity of livestock compared to any ecosystem in the world (Sankaran & Anderson, 2009). An important characteristic of the savanna ecosystem is its dynamicity (Skarpe, 1991). The communal rangelands wherein 76% of rural people stay comprises 70% of the savanna biome in South Africa. In these rangelands, resources and activities that are critical for people's wellbeing include livestock production, fuelwood collection and use, construction materials and implements, wild foods, medicines and craft materials (Shackleton et al., 2003).

In order to understand the relationship between vegetation attributes and how they are influenced by the environment there needs to be an understanding of the factors that influence vegetation (Austin, 2005). Khavhagali and Bond (2008) highlighted that there is still disagreement over what precisely determines the structure and the distribution of savannas. However, various biotic and abiotic factors have been identified to being playing a role and these include, resource-competition (e.g for nutrients and water), fire, climate, and herbivory (Scholes & Archer, 1997; Jones *et al.*, 2016). The determinants are categorized into primary (e.g climate and soil) and secondary (e.g fire and herbivores) (Aina *et al.*, 2013). Fire is not considered in this study due to its low intensity and small spatial extent in heavily grazed communal lands. Humans play a direct and indirect role in the alteration of the determinants of savanna ecosystems, and have influenced the structure and function of savanna ecosystems (Scholes & Archer, 1997). The vegetation structure is attributed to adaptations to the environment by biotic components and their influences on the abiotic components (Sala & Maestre, 1998). Dalle *et al.* (2014) also highlighted the role that the abiotic factors of topography, climate and soil plays in affecting vegetation composition in rangelands. The primary

determinants of climate and soil influence the moisture and nutrient availability and ultimately the quality and quantity of vegetation (Hopkins, 2000; Pandey & Singh, 1992). Therefore, the amount of moisture that is available at any point in time due to seasonal variation will have an impact on the soil moisture available with the resultant impact on the vegetation production.

Soil moisture availability and its vertical and horizontal distribution determines the ratio of woody and herbaceous vegetation as it determines its availability to plants, and these variables, in turn, are influenced by land usage and climate (Breshears & Barnes, 1999). Due to its criticality as a grazing resource, grass is very important when compared to other components of the herbaceous layer like forbs and sedges (Matney, 2015).

Topography is also an important variable that influences water availability or loss, and therefore determines plant distribution and diversity patterns. However, its scale dependence and the primary mechanisms by which it operates are not well understood (Ben Wu & Archer, 2005; Moesland *et al.,* 2013). When compared to abiotic variables, anthropogenic factors play a very significant role in affecting the vegetation composition, structure and its functioning (Grime, 1979). The influences of natural disturbances together with disturbances due to humans on landscape interactions have not received enough attention (Linderman *et al.,* 2006). Disturbance gradients in the communal rangelands are due to walking distance from settlements and livestock grazing patterns which are dictated to by herder behaviour and distance from water points (Dube & Pickup, 2001). Due to the spatial extent upon which the environmental determinants operate and interact in the savanna it is unclear of their exact influence on the vegetation patterns (Colgan *et al*., 2012). Many ecological studies have had an interest in establishing what each biotic and abiotic factor plays in influencing the structure and diversity of ecological communities along environmental and disturbance gradients (Anderson *et al.,* 2011). Although there is consensus on the social and economical importance of the savannas, their functioning, origin and nature are still not completely understood (Scholes & Archer, 1997; Jeltsch *et al.,* 2000).

There is a need to understand the relationship between herbaceous vegetation and environmental determinants in order to understand the composition of particular plants species in the environment within which it is studied (Mucina, 1997). Human impacts are shielded by spatial variability in topography, soil types, vegetation types and land use (Wessels *et al.*, 2007). Given the limited studies that have been undertaken in understanding the interactive effect of topography, rainfall and disturbance gradients on herbaceous vegetation in communal lands, this study seeks to address this

knowledge gap by specifically focusing on the communal areas located within the Bushbuckridge municipality, South Africa.

1.2 Aim, Objectives, Key Questions And Hypothesis

1.2.1 Aim of the study

The aim of this study is to investigate the individual and interactive effects of rainfall, topographical, and distance gradients on herbaceous vegetation composition and structure in a communal rangeland landscape.

1.2.2 Objectives, research questions and hypothesis

Objective 1: To determine how herbaceous vegetation composition and structure differ along a rainfall gradient in a communal rangeland.

Research Question

How do grass composition, species richness, species diversity and basal cover differ along a rainfall gradient in a communal rangeland?

Hypothesis

There is higher herbaceous species abundance, species richness, species diversity and basal cover in the high rainfall zone than in lower rainfall zone in the communal landscape.

Objective 2: To determine how herbaceous vegetation composition and structure differ along a topographical gradient in a communal rangeland.

Research Question

How do grass composition, species richness, diversity and basal cover differ along a topographical gradient in a communal rangeland?

Hypothesis

There is higher herbaceous species abundance, species richness, species diversity and basal cover in lowland areas than in upland areas in the communal landscape.

Objective 3: To determine how herbaceous vegetation composition and structure differ along a disturbance gradient in a communal rangeland**.**

Research Question

How do grass composition, species richness, species diversity and basal cover differ along a disturbance gradient across a communal rangeland?

Hypothesis

There is lower grass species composition, species richness, species diversity and basal cover in areas that are closer to the villages than areas further from the villages in the communal landscape.

Objective 4: To determine the combined effect of rainfall, topographical and disturbance gradients on the herbaceous composition and structure in a communal rangeland.

Research Question

How do grass species occurrence and basal cover differ across a communal landscape due to combined effect of rainfall, topography and disturbance gradients across a communal landscape?

Hypothesis

There is a difference in grass species occurrence due to rainfall, topography and disturbance gradients and higher basal cover on the downslope, high rainfall and less disturbed areas in the communal landscape.

1.3 Literature review

1.3.1 Determinants of herbaceous vegetation in savannas

Ecological studies seek, as one of the goals, the prediction of the spatial distribution and composition of species over the landscape (Bridge & Johnson, 2000). Various theories have been developed over the years to understand the ecological role that savanna determinants (biotic and abiotic) play in influencing and maintaining tree and grass ratios in the savanna (Bucini, 2010; Augustine, 2003). Their correlation with vegetation is critical in understanding vegetation composition and structure in a particular ecological space (Mucina, 1997). In their review, Scholes & Archer (1997) have highlighted three models for tree-grass interactions being, niche separation model, balanced

competition and disequilibrium models.

The interaction of tree and grasses, spatially and temporally, occurs by various ways with a number of possible outcomes and no definite predictive model (Scholes & Archer, 1997). In a mixed tree-grass system in the savanna (Figure 1), the primary determinants (fire and herbivory) and secondary determinants (water and nutrient supplies) were specified by Scholes and Walker (1993) as being vital in influencing the savanna structure and function. There is a relationship between geology, water and nutrient (Cole, 1982). Geology is understood to predetermine different vegetation that can be found in a particular ecological areas (Wiegand *et al.*, 2006).

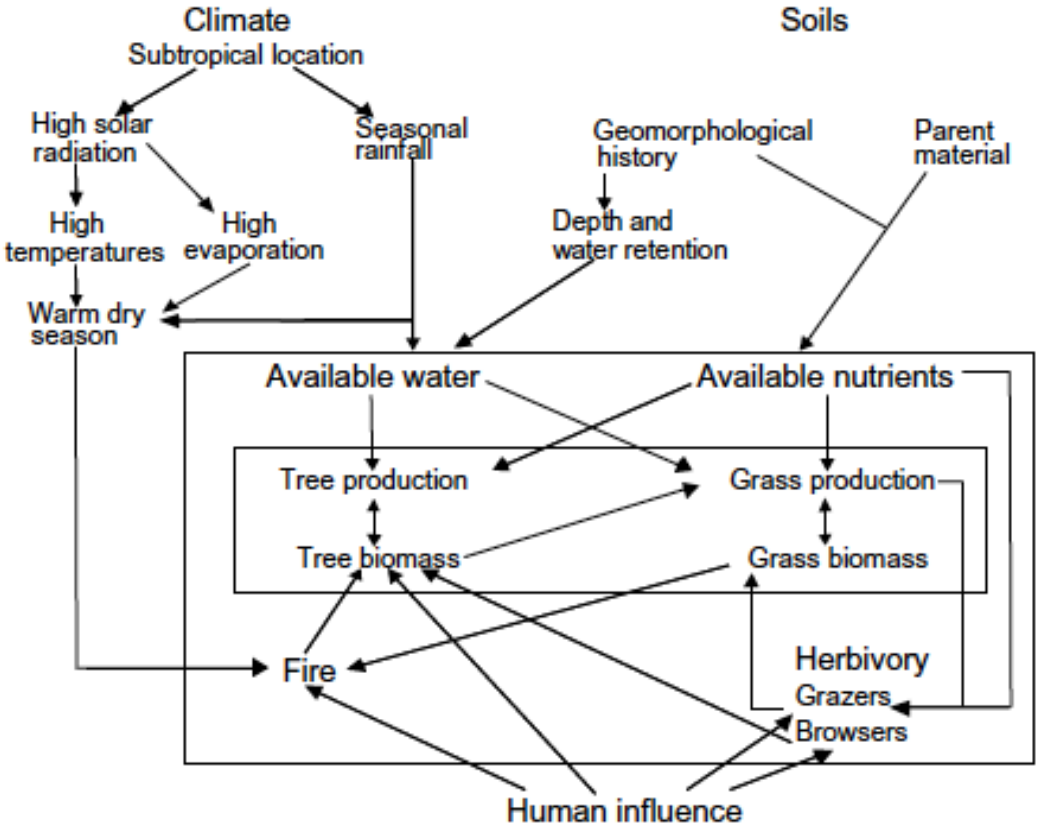


Figure 1: Key-driving variables for mixed-tree grass systems. Numerous factors that affect the abundance of grasses and woody vegetation in dry lands (Scholes & Walker, 1993).

1.3.1.1 Impact of rainfall on herbaceous composition and structure.

In the semi-arid vegetation communities, rainfall plays a primary role in influencing the structure, composition and functioning of vegetation communities (Belsky, 1990; Gentry, 1988; Anderson *et al.*, 2007). In arid areas, the high variability of rainfall is correlated with inherent short-term availability of soil water as resource and therefore this becomes a key factor in long-term vegetation

dynamics (Wiegand & Jeltsch, 2000). The root niche separation model as highlighted by Scholes and Archer (2007) holds that water is the primary determinant that limits the ratio of trees and grasses due to their differential access to it. Therefore, the proportion of trees to grasses is influenced by the vertical soil moisture differential within set environmental conditions, with the amount of trees increasing as the amount of soil moisture increases (Sankaran *et al.*, 2004).

Moisture is used as a surrogate for the presence of water in the soil (Pausas & Austin, 2001). In arid and semi-arid environments, species richness has positive relationship with water availability. In a Californian study, Richerson & Lum (1980) found positive logarithmic relationship between rainfall and species richness. Adler and Levine (2007) also found similar positive relationship, where it was established on the effect of 100 mm increase in rainfall on species per m^2. In another study, Traill *et al.* (2013) highlighted data to indicate a relationship between diversity and productivity, with an asymptotic increase in species richness with increased rainfall. This effect could be due to rainfall indirectly influencing the abiotic and biotic factors (Adler & Levine, 2007). An increase or decrease in mean annual precipitation will have an effect on species composition in the long-term (Steenekamp & Bosch, 1995). Noy-Meir (1979) in emphasising the effect of rainfall has reported that in the Negev region, 5000 years of grazing had had no significant effect on the vegetation structure, whereas fluctuations in rainfall patterns did. In the savannas, there is variation in rainfall distribution (Ward *et al.*, 2004; Sharon, 1981; Prins & Loth, 1988). This can lead to patchy vegetation patterns (Ward, 2005). Precipitation is usually one of the major driving forces for vegetation production and growth in the semi-arid and arid areas and is generally highly correlated with herbaceous vegetation (Snyman, 1998; Klein & Roehrig, 2006).

The composition of perennial and annual grasses in the semi-arid savanna of southern Africa, is controlled by availability of water with drought causing a decrease in perennial grasses whilst leading to increase in annual grasses (Hochrasster *et al.*, 2002). The increase in annual grasses is attributed to the ability to maintain seed sources during drought and opportunistic response to favourable conditions (Bowers, 1987; Danin & Orshan, 1990). However, such shifts may be temporary (Hild *et al.*, 2001). Annual herbaceous plants mostly have shallow roots and are therefore more dependent than perennials on available water stored in the upper soils layers (Schenk & Jackson, 2002). In the longterm these limitations may explain the advantage that perennials might have on the annuals in high soil moisture conditions.

Higher rainfall has been observed to increase grasses tuft diameter and reduce intertuft distance (Buitenwerf *et al.*, 2011), therefore implying positive influence of rainfall on grass basal cover.

Angassa *et al.* (2010) also reported on the influence of rainfall on basal cover. In a study by Moyo *et al.* (2011) it was established that herbaceous vegetation production and grass basal cover were episodic and closely linked to rainfall. Hydrological processes together with biological and atmospheric processes directly influences soil moisture availability which control processes such as nutrient absorption, transpiration and primary production (Noy-Meir, 1973). Soil moisture is commonly recognized as an important variable that links rainfall to vegetation growth (Jamali *et al.*, 2011). Overall, large precipitation events lead to significant increase in soil moisture, whilst less rainfall leads to reduced water ingress into the soil (Schwinning & Sala, 2004). In the areas that have more evaporation than precipitation water availability to plants is dependent on edaphic and local climate factors (Casper & Jackson, 1997). The herbaceous vegetation density is mostly abundant at the wettest part of the moisture gradient (Schenk & Jackson, 2002). The availability of water influences herbaceous production, with less water areas having less production compared to areas with high availability of soil moisture. Soil moisture is critical in the physiognomy and physiology of plants and therefore affects the composition of species and their diversity (Hettenbergerová *et al.*, 2013).

1.3.1.2 Impact of catenal position on herbaceous vegetation composition and structure.

Savannas consist of catena sequences, which generally have distinct upland and bottomland vegetation (Colgan *et al.*, 2012; Parsons *et al.*, 1997; Scholes & Walker 1993; Shackleton, 2000; Witkowski & O'Connor, 1996). Catena is referred to as a typical soil sequence, which is localised on the slope, homogenous with regard to climate and geology (Rozek, 2013). Catenal variation in soil properties on hillslopes forms regular and repeated sloping patterns from crest to toeslope (Milne, 1935). The catenal influence on resource availability together with soil characteristics have effect on vegetation resulting in differentiation in species composition, vegetation pattern and their adaptations to the local environment (Offiong *et al*., 2011; Parsons *et al.*, 1997; Bohlman *et al*., 2008 & Costa *et al*., 2005). The upslope and downslope areas have differing vegetation species composition (Shackleton, 2000; Fraser *et al.*, 1987; Witkowski & O'Connor, 1996). In the Lowveld, on fine textured soils, the dominant herbaceous layer is comprised of *Panicum maximum, Digitaria eriantha,* and *Aristida congesta* while brackish bottomlands support *Sporobolus nitens, Urochloa mosambicensis* and *Chloris virgata*.

Catenal position affects water availability and controls its proximity to the groundwater table or local drainage pattern and also have an influence on species richness (Rozek, 2013; Acharya *et al*., 2011 & Lomolino, 2001). A study by Fujita *et al.* (2009) also highlighted the positive effect of

bottomlands on the species richness and negative effect on the upper slope. There is a difference in nutrient availability in upslope and downslope sites, with the upslope areas containing less organic matter and moisture than downslope areas. This is due to the fact that the nutrients are mobilized by water to the downslope areas (Mlot, 1990). Generally, bottomlands have been found to have higher moisture content than the upland, a study by Kirkman *et al.* (2001) highlighted the importance of moisture as a limiting resource and its effect on species richness. In Rozek (2014), it was highlighted that topography and soil parent material determines the soils and vegetation cover. Catenal influence on vegetation occurs directly and indirectly, by creating breaks in vegetation permanently and by its influence on disturbance factors and succession pathways (Swanson *et al*., 1998; Turner, 1989). The environmental variation within landscapes may be manifested in differing vegetation spatial pattern (Jobbagy, 1996).

The catenal differences in soils from upslope to downslope give rise to a succession of vegetation types with differences in structural and floristic patterns (Offiong *et al.*, 2011). The downslope areas in communal rangelands in Bushbuckridge, South Africa, were found to have higher tuft density, basal area and poor palatable species compared to upslope areas (Parsons *et al*., 1997). Minchunas *et al.* (1989) previously reported on the greater difference observed in vegetation community between catenal positions, particularly on the ungrazed areas.

In a study by Penny *et al.* (2013), it was found that vegetation pattern was oriented in the same direction as topographic slope and it was further established that downslope water accumulation might play a role in vegetation pattern properties. Because of topographical affects on soil for example, slope, aspect and micro-topography will affect soil drought and moisture (Heydari & Mahdavi, 2009). It is important to fully understand the influence that catenal gradients have on aspects such as vegetation spatial patterns, plant life forms and species richness so as to enable development of better management options for vegetation biodiversity conservation and its utilization (Ren *et al.*, 2012).

1.3.1.3 Impact of grazing on herbaceous vegetation composition and structure

Livestock grazing has substantially altered the composition and structure of grasslands and savannas throughout the world (Briske & Noy-Meir, 1998). In many parts of the world land use and management actions trigger a strong effect on vegetation cover and diversity patterns of ecological communities (Hanke *et al*., 2014). As one of the land use types, grazing by domestic herbivores has both notable and extensive impacts on plant communities (Díaz *et al*., 2001).

The impacts of grazing on vegetation are normally evident at the population or species level. The differential and selective grazing due to herbivores on the composition and structure of vegetation may favour spreading of less abundant but grazing tolerant species (Sternberg *et al*., 2000). The degree of impact due to grazing can be measured by measuring changes in vegetation species composition or species diversity and cover that occur as result of long term animal grazing (Sankaran *et al*., 2005). There still no clarity regarding the effect of grazing on plant diversity despite extensive background on the subject (Hanke *et al*., 2014). On the other hand it was established by Rutherford *et al.* (2012), that with high communal land utilization due to grazing there was no significant changes in species richness when compared to areas that were lightly utilized.

Grazing affects vegetation directly or indirectly. The direct effect of grazing on vegetation is by trampling and defoliation whilst indirect effect is by changes in growth conditions. Such effects occurs on the plant physiological and morphological level as indicated in Figure 2 (Torrano & Valderrabano, 2004). The indirect effect ultimately reduces the vigour and presence of the dominant species (Sternberg *et al*., 2000).

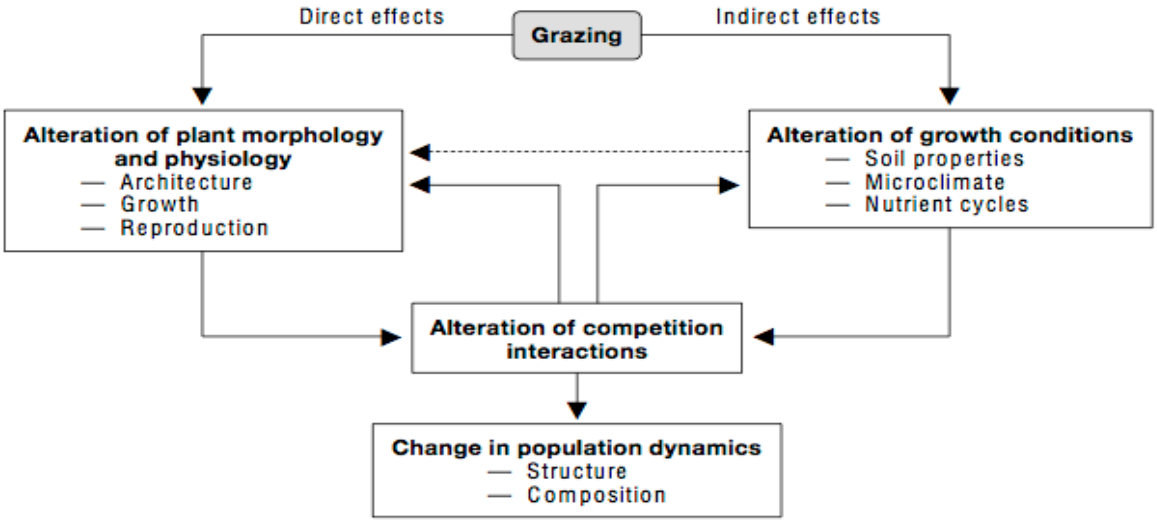


Figure 2: Relationship between direct and indirect effect of grazing on vegetation (Torrano & Valderrabano, 2004).

The vegetation structure is the three dimensional arrangement of plant components, individual plants or species at fines scale and at larger scale through compositional and spatial arrangement that is affected by defoliation, trampling, and excreta from animals (Marriott & Carrere, 1998). It is in the leaf areas and basal area where grazing affects the vegetation structure, also changes in growth forms is indirectly due to herbivory (Sala, 1988). The loss of vegetation cover as a result of

overgrazing results in decreased forage for livestock (Macharia & Ekaya, 2005), and increase in denuded areas. The effect of grazing on grass basal cover as evidenced by Ethiopian study (Angasssa *et al*., 2010) indicated that grazing areas when compared to enclosed areas had reduced grass basal cover.

Perennial grasses generally dominate other life forms and provide important ecosystem services including being grazed by herbivores and in prevention of soil erosion (Zimmerman *et al*., 2009). In areas that are under grazing perennial grasses tend to be replaced by annual grasses (Milchunas & Lauenroth, 1993). Though perennial plants are abundant in grazing environment there is no much information on their compensation mechanism (Del Val & Crawley, 2005). In a study by Makhabu and Marotsi (2012), it was reported on the increase in annual grasses over perennial grasses grazing in disturbed sites but subsequently gradually declined. Other observations have been made in the species change in grazing gradients with a replacement of perennial grasses by annual grasses in semi-arid areas of East Africa and southern Africa (Lowveld, Mpumalanga). There was also evidence of change in reduction in tuft sizes reported (O'Connor & Pickett, 1999; Parsons *et al*., 1997). Depending on their response to grazing, persistence or disappearance of plants can be categorized as increasers and decreasers (Wesuls *et al*., 2013). This classification of plants is based primarily on their response to biotic factors (Guretzky, 2005). Decreaser grass species respond when there is insufficient or extensive disturbance, whilst inceaser I and increaser II respectively increase in abundance with minimal and heavy disturbance, whether due to fire, grazing or by combination. When selective grazing occurs it may lead to abundance in Increaser III species (Little *et al*., 2015).

The impact of grazing influences initially the decreaser plant species followed by an effect on increaser plants. When grazing pressure is increased, palatable perennial grasses are reduced causing a shift to less palatable perennials and annual grasses (Owen-Smith, 1999; Joubert, 1997). In the long term, under continued grazing, the desirable plant species will be lost resulting in an increase in invader species and bare ground (Ünal *et al*., 2011).

The impact of livestock grazing on plant communities have been the subject of debate worldwide (Hayes & Holl, 2003). Noy-Meir and Seligman (1979) has reported that in the Negev region 5000 years of rainfall fluctuations had had an effect on vegetation structure when compared to grazing. However, a study by Serneels *et al.* (2007) found that change in land use led to some response in vegetation. The responses of ecosystems to livestock grazing that have been observed elsewhere include desertification, woody species encroachment and deforestation (Asner *et al*., 2004). Various factors, that include both biological and physical factors when interacting with herbivory have an

effect on the ratio of woody-herbaceous vegetation (Sankey, 2007). Increased livestock densities (stocking rate) resulted in changes in both land cover and vegetation production. (Serneels *et al*., 2007).

Ultimately, any changes that occur on the vegetation cover impact on the balance of energy, water, and the geochemical fluxes at various spatial scales. These changes will inevitably influence the sustainability of natural resources and socio-economic activities (Vescovi *et al*., 2002). In rural areas in developing countries, the natural environment is critical as a source of livelihoods for the people's sustenance, in marginal areas there is heavy reliance on land resources (Hunter *et al*., 2010; Tabassum *et al*., 2012). These resources are used for people's own direct use and as a means to generate income. However, these are coming under increasing pressure for reasons such as poverty, high human population densities, and the weakening of traditional authorities that have historically been responsible for the control of access to natural resources in these parts of the country (Twine *et al*., 2003). One of the objectives of the study is intended to determine the indirect effect of humans on the herbaceous vegetation through pastoralism.

1.3.2 Overview of the communal lands in the former homelands

The former Bantustans areas which comprises of almost a quarter of land in South Africa are constituted mainly of communal rangelands. These areas are where a large population of black people were confined to (Yawitch, 1988), as part of the then apartheid government's separate development policy. During the apartheid era the chiefs had control over the use and protection of the natural resources and were afforded support by government through its agricultural officials (Cousins *et al*., 2007).

The environmental state and history of the former Bantustan areas was fundamentally different when compared with the conservation areas under state control or with white owned farms that were situated around the Bantustan areas (Hoffmann, 2014). The communal lands have been exposed to overgrazing since the 1960's and the areas closer to the villages are particularly overgrazed due to goats that forage closer to the villages (Twine *et al*., 2002). The communal grazing lands are freely accessible and utilized by all farmers and are supportive of cattle and other domestic animals in a continuous grazing system (Parsons et al., 1997). The communal lands are known to have high stocking rate of 2-4 times greater than the required rate and overpopulation together with loss of palatable species due to overgrazing (Shackleton et al., 2001; Shackleton, 1993; Meadows & Hoffman, 2002; Rhode *et al*., 2001). High stocking rates results in excessive trampling along

footpaths and around water points, which can worsen drought effects by increasing perennial grass mortality and resulting in changes in species composition (Palmer & Bernett, 2013; O'Connor, 1994; O'Connor, 1995). Other effects include erosion and decreased productivity. As a result of overgrazing in the communal lands, soil erosion is now major concern with soil formation being exceeded by soil loss (Van der Merwe, 1995).

1.3.3 Vegetation composition, structure and its measures

Composition is the assemblage of plant species that define the vegetation in a particular ecological space (Martin, 1996). Together with the species assemblages, it can be defined based on the relative abundance of species per given area in terms of relative cover, relative density, relative weight, etc. The herbaceous layer in the savanna includes annual and perennial forbs and grass species. However, the annual species are usually in the arid areas (Von maltitz & Scholes, 2006). Species diversity is one of the measures of ecological diversity that takes into account the community measures of species evenness and richness (Hamilton, 2005). Species richness measures the total number of species in the community whilst evenness gives an indication of how evenly the individuals in the community are distributed over the different species (Heip *et al.*, 1998). An understanding of the patterns and processes in species diversity is critical for ecosystem function and in conservations measures (Fraser *et al*., 2014) and this has always been of interest to the ecologists. Species diversity measurement indices aim to describe general properties of communities that enables comparison of different regions, taxa, and trophic levels. Notwithstanding their importance in environmental monitoring and conservation, there is still no consensus on which indices are more useful (Morris *et al*., 2014). Simpson (D_1) and Shannon (H') indices are some of the commonly used diversity indices. Simpson's index is the commonly used diversity index (Magurran, 1991). It measures the probability that two individuals selected at random from a sample belong to different species.

Generally, vegetation structure takes into account the composition of plant community based on specific morphological characteristics (Martin, 1996). In order to make a determination of the long term plant productivity habitat status an assessment is made on the plant structural stages. (Schulz *et al*., 2009). The sampling of vegetation is undertaken to detect and predict changes in plants in response to environmental change or management action. The vegetation sampling metrics include amongst other frequency of occurrence. Density refers to the numbers of plants that can be measured per unit area (Higgins *et al*., 2010). It therefore can be used to measure a variety of vegetation life-forms like, sedges, grasses (perennial or annual) and trees in a particular environment. The measures

can be achieved by quadrats or plotless methods. Frequency describes the distribution patterns of a species on a plot or within a stand, i.e., clumped vs. dispersed (Elzinga *et al*., 1998). It can be calculated from data collected at multiple scales.

1.4 Structure of the thesis

This thesis is presented in five chapters. To achieve the objectives outlined, this research report is structured as follows:

Chapter 1: presents introduction and literature review, which includes sub-sections on determinants of savanna vegetation and overview of state of the communal land in the former homelands.

Chapter 2: presents methodology, including description of the study area and data analysis (methods that were employed to accomplish the objectives).

Chapter 3 : offers results in difference in grass species richness, species diversity and basal cover as a result of rainfall, topography, disturbance gradients and the combination thereof.

Chapter 4 : offers discussion and interpretation of the results and relates them to findings from other studies.
Chapter 5: based on the findings made this chapter offers *c*onclusion and includes suggestions on future studies.

CHAPTER 2

2 METHODOLOGY

2.1 Study Area

The study area is located in the communal rangelands of the Bushbuckridge Local Municipality (BLM), which is situated in the northern side of South Africa's lowveld semi-arid savanna region in the Mpumalanga Province. BLM forms part of Ehlanzeni district. Historically, Bushbuckridge district was part of the former Bantustan self-governing system during apartheid era in the districts of Mhala in Gazankulu and Mapulaneng in Lebowa. The area is characterized by high population density, poverty and land-use practices typical of African savanna rangelands such as cattle overstocking and intensive harvesting of firewood (Giannecchini *et al*., 2007; Shackleton, 2000). As per 2011 census figures, it was estimated that at least 99.5% of people living within the municipality are black African. The area consists of 65 settlements, varying in size from fewer than 100 homesteads to over 800, surrounded by some 1565 km^2 of communal rangeland (Shackleton, 2004). The tenure system in this region as within all former homelands system is communal. Communal grazing lands are supportive of cattle and other domestic livestock, with several communal farmers having access to the same grazing area (Parsons *et al*., 1997). The traditional leaders who are in authority over the land determine the local land use patterns (Shackleton & Shackleton, 2000). The animal stocking rate is close to ecological carrying capacity at 0.88±0.09 livestock units (LSU) per hectare (ha) (Parsons *et al*., 1997). Subsistence livelihoods are practiced, and land utilization tends to be higher closer to the villages (Shackleton *et al*., 1994). Land uses in the area are accounted as communal rangelands (64.7%), nature conservation (12.9%), plantation forestry (10.8%), dry-land arable agriculture (6.6%), irrigated arable agriculture (2.2%) and residential (2.8%) (Shackleton *et al.*, 1995).

The study site includes 21 villages and over 11,000 households. However, this study was undertaken in only nine villages, which lie along a rainfall gradient as shown in Table 1 with three villages per rainfall zone.

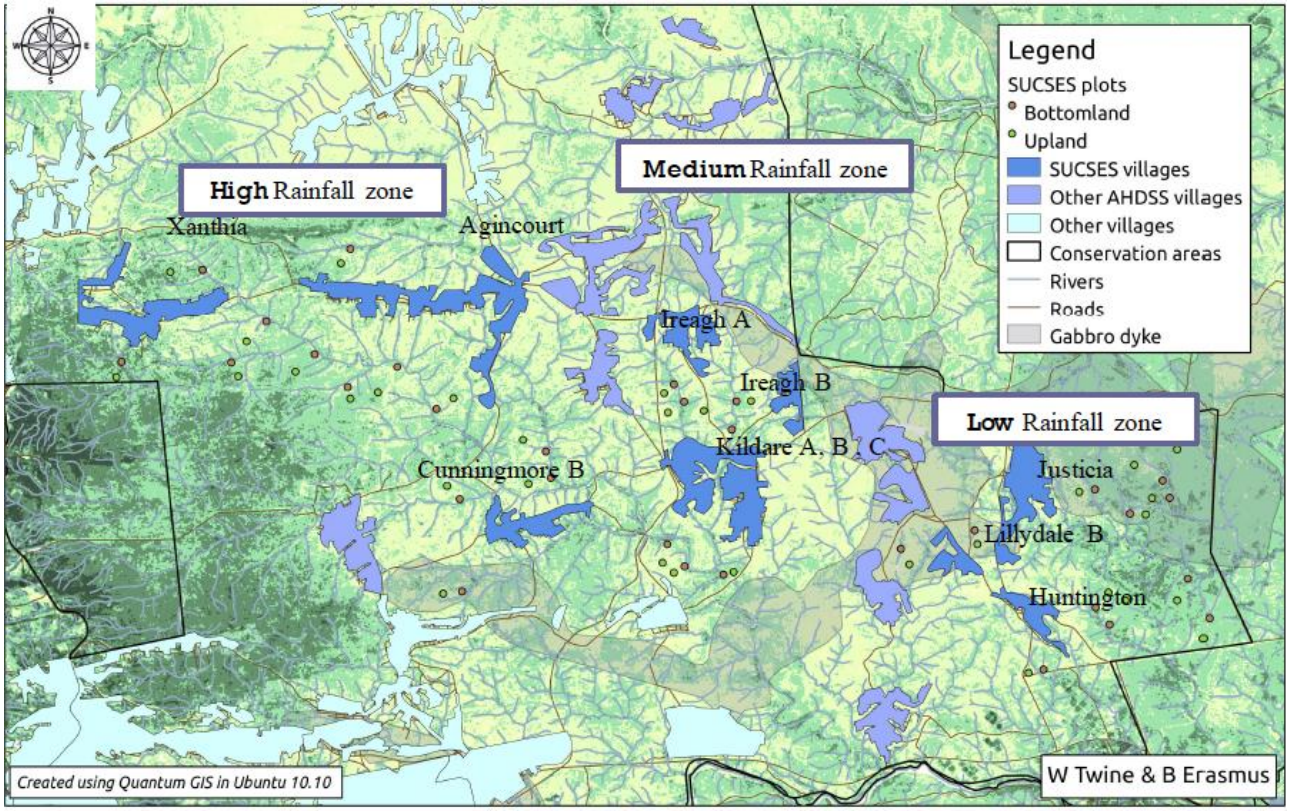


Figure 2: Map showing the study site and surrounding areas in Bushbuckridge, Mpumalanga Province in South Africa.

2.2 Geology and topography

The lowveld, which extends from the footslope of the Drakensberg escarpment on a regional scale, lies on average 300m above sea level (Venter & Bristow, 1986). The area is characterized by topography that is gently undulating (hills in the west) with the terrain become flatter toward the east (Wessels *et al*., 2011; Shackleton, 2000). The area is further characterized by granite and gneiss as dominant geology with local intrusions of gabbro (Venter *et al.*, 2003). Granite landscapes are known to have nutrient-poor soils (Wessels *et al.*, 2011). The terrain morphology of the lowveld is determined largely by geological structures and differences in resistance of various rock formations against weathering (Venter & Bristlow, 1986). The catenal sequence has soils in the interfluves that are dystrophic and shallow, with those in the bottomslopes being deeper and clayey eutrophic soils, and are often duplex in structure (Scholes, 1987). Hydrologically, the catenas are linked hillslope soils with dynamic solute, particle and colloid mobilization processes, with resultant soil differentiation along their slopes (Khomo *et al.*, 2011; Milne, 1935).

2.3 Climate

The lowveld climate is linked to the regional climate of the subcontinent, which then is influenced by anticyclonic conditions systems that moves semi-rhythmically over southern Africa from the western side to east (Venter & Gertenbach, 1986). The region is also characterized by hot humid summers (the rainfall season being October-April) and mild winters (Madubansi & Shackleton, 2007; Shackleton *et al*., 1994). Rainfall occurs mainly in the form of convectional thundershowers, sometimes with prolonged cyclonic showers. The annual mean rainfall ranges from 1200 mm at Drakensberg escarpment in the lowveld, reducing to 550 mm on in the east over a linear distance of 100 km (Shackleton, 2000). The mean annual temperature is approximately increases 22 °C with a decreasing trend from northeast to southwest.

The villages under study are stratified by rainfall zones as indicated in Table 1 below.

Table 1: Location of villages per rainfall zones.

Village	**Rainfall Zone**	**Mean Annual Rainfall (mm)**
Justicia, Lillydale B, Huntington (East)	Low	<600
Ireagh A, Ireagh B Kildare A,B,C (Mid)	Medium	600-700
Xanthia, Agincourt Cunningmore B (West)	High	>700

2.4 Vegetation

The natural vegetation is open, deciduous savanna woodland and is predominantly granite lowveld, even though the region also contains gabbro grassy bushveld, and legogote sour bushveld (Mucina & Rutherford, 2006; Rutherford *et al.*, 2006). The dominant tree genera are *Acacia, Albizia, Combretum, Grewia, Sclerocarya* and *Terminalia* (Madubansi & Shackleton, 2007). Common plant species on the granite Lowveld uplands include: *Terminalia sericea, Combretum zeyheri* and *C. apiculatum* whilst in the bottom slopes are characterised by *Acacia nigrescens, Dichrostachys cinerea and Grewia bicolor* (Rutherford *et al*., 2006). The dominant herbaceous layer is comprised of *Panicum maximum, Digitaria eriantha,* and *Aristida congesta* while brackish bottomlands support *Sporobolus nitens, Urochloa mosambicensis* and *Chloris virgata* on the fine textured soils.

Terminalia sericea occurs at seep lines where convex topography changes to concave, with *Eragrostis gummiflua* occurring in the undergrowth (Mucina *et al*., 2006)

2.5 Data Collection

2.5.1 Herbaceous Vegetation Sampled

The data used in this study were collected during February and March of 2012 from each village as part of Sustainability in Communal Socio-Ecological Systems (SUCSES) project. The aim of the project is to clearly understand humans and the environment dynamic interactions in South Africa's rural areas. Random stratified sampling was undertaken based on rainfall zone and topographical position, with pairing sample sites on the sampled slope (one upland and one on the bottomland). A total of 100 points were sampled in each of the 56 plots. Twenty plots were sampled in the dry east zone (Justicia, Lillydale B, Huntington), with ten (10) plots on the upland and ten (10) plots on the downslope position. Eighteen (18) plots were sampled in the mesic zone (Ireagh A, Ireagh B, Kildare A, B, C) with nine (9) on the upslope and nine (9) on the downslope positions. Further eighteen plots were sampled in in the moist wet zones (Xanthia, Cunningmore B, Agincourt) with nine (9) plots each on the upslope and downslope positions. For each plot four line transects each 25 m long radiating out from the plot centre along cardinal compass bearings were laid. The GPS coordinate of the central point was taken and staked with a metal rod to facilitate subsequent ease of location. At each metre, the following were recorded: whether the point fell under herbaceous canopy, on grass tuft base, and on leaf litter. However, for the purpose of this study the following data was collected, annual grass, perennial grass, sedge, herby forb, woody forb or geophyte. Frequencies were converted to percent per site. At each metre point, it was recorded whether the nearest herbaceous plant was an annual grass, perennial grass, sedge, herby forb, woody forb or geophyte. The grass tuft species nearest to the metre was recorded. The species and distance to tuft of nearest perennial grass tuft was recorded. The distance to nearest perennial grass was used as an index of density of perennial grass tufts. The distance between random point to the nearest tuft is a function of tuft density. The distance from each plot to the nearest village was measured by use of Google Earth ruler tool. Distance from village was used as a proxy for intensity of disturbance by humans and livestock (assumed to be highest close to the village).

2.6 Data Analysis

Statistical analysis was performed using version 23 of IBM ‘s SPPS (Statistical Package for the Social Science). Measures of composition and structure were dependent variables. Rainfall zone, topographical position and distance from village were independent variables. Composition was quantified by calculating percentage of annual grass, perennial grass, sedge, herby forb, woody forb or geophyte per plot. Species richness and Simpson’s Diversity Index was also calculated per plot. Measures of spatial structure was derived from calculation of density, which was derived from distance measured to nearest tuft of nearest perennial grass. Simpson’s Diversity Index was used to compare diversity indices across different environmental gradients. Simpson ‘s Diversity Index was calculated by using the following formula: $\lambda=\sum ni(ni-1) /N (N - 1)$. MS Excel was used to graph the species abundance per rainfall and topographical zones.

Shapiro-Wilk tests were done to determine normality of data. One way Analysis of Variance (ANOVA) with post-hoc Turkey test was done to determine significance of differences between means where data were normal. Where applicable log transformation was done for non-normal data so that ANOVA could be used. In case where log transformation did not result in normalized data, Kruskal-wallis was done. Mann-Whitney U was used to differentiate between pairs that had significant means after Kruskal-Wallis test. These statistical test were used to test for significant difference in the means of composition (percentage of annual grass, perennial grass, sedge, herby forb, woody forb or geophyte; species richness and Simpson’s diversity Index) and means of structure measures (perennial grass tuft and basal cover) between rainfall zones and distance gradients. T-test was used to compare means of composition and structure measures between topographical positions where data were found to be normal. Factorial ANOVA was used to determine combined effect of rainfall, topographical and distance gradients on structure of herbaceous vegetation. Alternatively, Mann Whitney U was used where data was found to be not normal. Linear regression was used to explore relationship between species abundance and distance gradient. The simultaneous effect were explored for using multifactorial ANOVA for those variables that were normally disturbed.

Canonical correspondence analysis is a multivariate statistical method that compares community composition with known environmental variation (ter Braak, 1986). It is a direct gradient analysis that allows for arranging species along environmental variables to establish relationship of environmental gradients and species composition. The combination of environmental variables are linearly arranged together with distributions of the species where they are maximally separated (ter

braak, 1987). Canonical correspondence analysis was accomplished using CANOCO version 5 computer program. CANOCO 5 was further used to conduct non-metric dimensional scaling on all species data and top-five species in rainfall and topographical gradients data.

CHAPTER 3

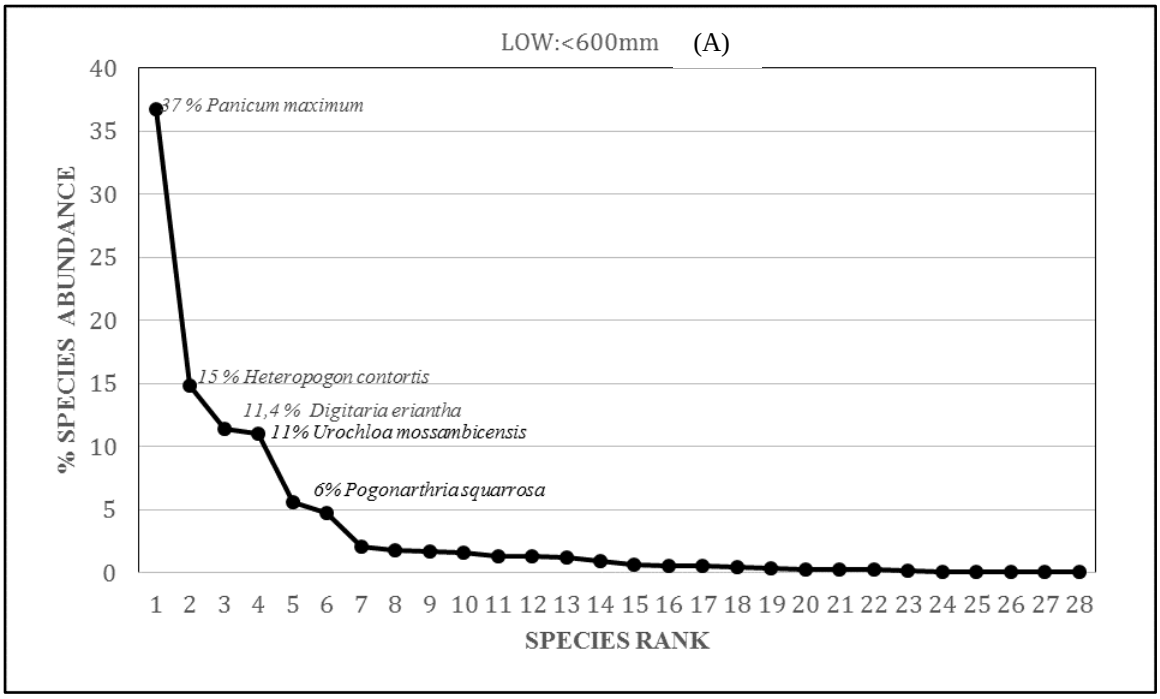
3 RESULTS

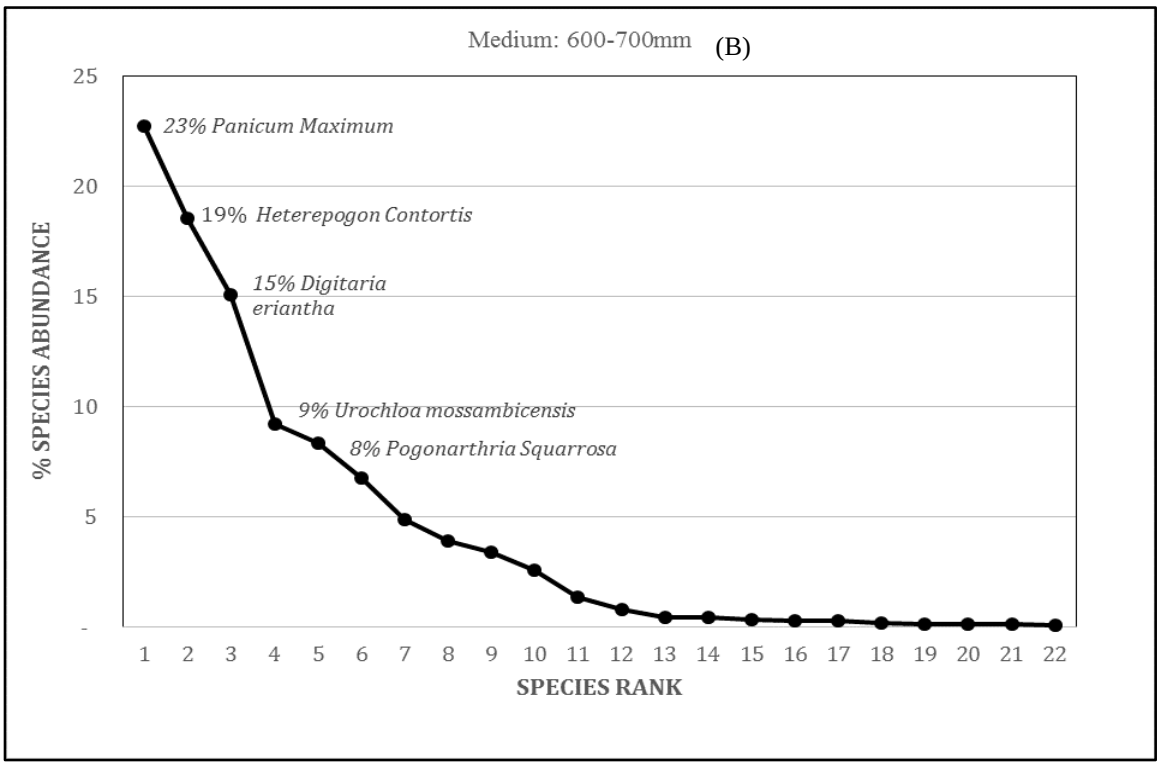
The study investigated the individual and combined effect of rainfall, fine-scale topographical and disturbance gradients on the vegetation composition and structure in the communal land of Bushbuckridge. The presentation of the results is as per various topics and this section commences with the findings on the composition and structure of herbaceous vegetation along rainfall gradient. This is followed by the results of composition and structure of herbaceous vegetation along a topographical gradient. Following this, a presentation is made on the effect of disturbance gradient on the composition and structure of herbaceous vegetation. Lastly, the findings on the determination of combined effect of rainfall, topographical and disturbance gradients on the composition and structure are presented.

3.1 Composition and structure along a rainfall gradient

3.1.1 Composition

The high rainfall zone, which is represented in this study by the villages Xanthia, Agincourt Cunningmore (west), had higher species richness than medium (mesic) and low rainfall zones (Figure 3). The high rainfall zones had 17% more species than low rainfall zones and 33% more species than the medium rainfall zone. The following species were found to be the top five most abundant species in all rainfall zones: *Panicum maximum (decreaser)*, *Heteropogon contortis (increaser)*, *Digitaria eriantha (decreaser)*, *Urochloa mossambicensis (Increaser)* and *Pogonarthria squarrosa (Increaser)* (Figure 3). Of the top five most abundant species *Panicum maximum* was the most abundant (Species Rank 1) in all rainfall zones whilst *Pogonarthria squarrosa* (Species Rank 5) was the least abundant in all rainfall zones. In the low rainfall zone, the top five abundant species accounted for at least 80% of all species, with the medium rainfall zones accounting for 74% of the top five abundant species. The top five abundant species accounted for 66% of all species in the high rainfall zone. Therefore, the percentage of the top five dominant species decreased with an increase in mean annual rainfall. The decreaser species accounted for 60% of the top five abundant species and the increasers species 40% species in the low rainfall zone. Within the zones with medium rainfall the decreaser species accounted for 51% of the top five abundant species, whilst in the high rainfall zones the decreaser species accounted for 48% of the top five abundant species. This shows that the decreaser species decreased with increase in mean rainfall, whilst the increaser species increased with an increase in mean annual rainfall.


LOW:<600mm
(A)
% SPECIES ABUNDANCE
SPECIES RANK
37 % Panicum maximum
15 % Heteropogon contortis
11,4 % Digitaria eriantha
11% Urochloa mossambicensis
6% Pogonarthria squarrosa


Medium: 600-700mm
(B)
% SPECIES ABUNDANCE
SPECIES RANK
23% Panicum Maximum
19% Heterepogon Contortis
15% Digitaria eriantha
9% Urochloa mossambicensis
8% Pogonarthria Squarrosa

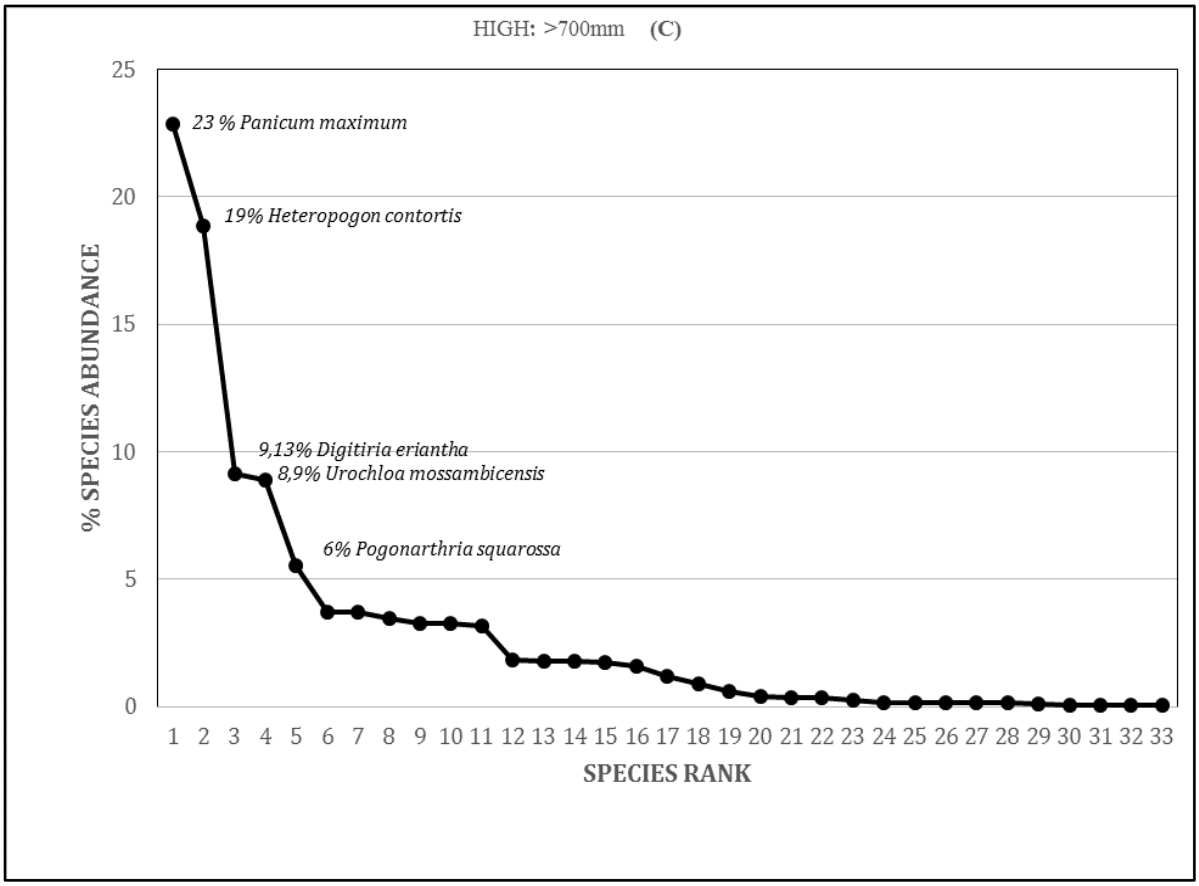


Figure 3: Species Ranking Abundance Curves across all low (A) (<600 mm), medium (B) (600-700 mm) and high (C) (>700 mm) rainfall zones in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

The frequency distribution of all species from Medium vs Low, Medium vs High and High vs Low rainfall zones did not reveal any significant differences (Table 2). Similarly, the frequency distribution of five top common species, namely *Panicum maximum*, *Heteropogon contortis*, *Digitaria eriantha*, *Urochloa mossambicensis* and *Pogonarthria squarrosa* from Medium vs Low, Medium vs High and High vs Low rainfall zones was not different (Table 3).

Table 2: Two sample Kolmogorov-Smirnov (KS) comparisons of all species composition distributions between rainfall zones in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Rainfall Zones	**Kolmogorov-Smirnov(K-S) Test**
	p-Value
Low Vs Medium	0.476
Medium Vs High	0.593
Low Vs High	0.933

Table 3: Two sample Kolmogorov-Smirnov (KS) comparisons of top five common species composition distributions between rainfall zones in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Rainfall Zones	**Kolmogorov-Smirnov(K-S) Test**
	p-value
Low vs Medium	0.819
Medium vs High	0.819
Low vs High	1.000

The ordination diagrams of non-metric dimensional scaling indirect gradient analysis, shows that the species composition of sampling plots for the all and five most common species is influenced by rainfall zones (Figure 4). The plots are segregated by species abundance along the west (wet) – mid (medium) – east (dry) gradient (x axis).

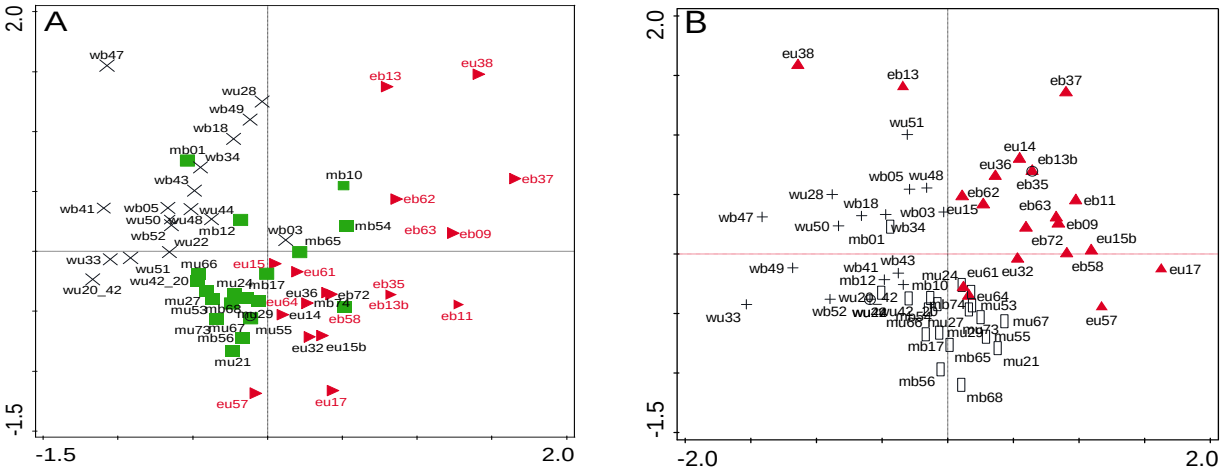


Figure 4: Non-Metric Dimensional Scaling for pooled species data (A) and top five common species across rainfall zones in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Graph A: Species Symbols: High Rainfall Zone (×), Medium Rainfall Zone (■), Low Rainfall Zone (►) Graph B: Top five common Species: High Rainfall Zone (+), Medium Rainfall Zone (□), Low Rainfall Zone (▲).

Mean species richness increased with increasing rainfall zone, and Analysis of Variance (ANOVA) showed that there was significant difference between individual rainfall zones, $F(2;53)=16.88$, $p=<0.001$ (Figure 5A). Post-hoc analyses were undertaken and it was established that the mean species richness in low and medium rainfall differed significantly ($p=0.038$), so was between low and high rainfall zone ($p<0.001$). However, the mean species richness between medium and high rainfall zone did not differ significantly ($p=0.07$). The mean Simpson's Diversity Index (SI) across

the rainfall zones was significantly different, $F(2;53)= 6.15$, $p= <0.001$. It was significantly different between low and medium rainfall zones (p=0.008) and between low and high rainfall zones (p=0.009), but not between medium and high rainfall zones (p=0.9) (Figure 5B). It was relatively higher in both medium and higher rainfall zones than in the lower rainfall zone. The results of Kruskal Wallis test indicated that there was significant differences in the mean rank of the perennial grass percentage composition across all rainfall zones, $\chi 2(2)=10.4$, p=0.006. It was significantly different between low and high rainfall zones (p=0.001) but not between medium and high rainfall zones (p=0.106) and between low and medium *(p=0.123).* The mean percentage composition of perennial grasses was highest in all rainfall zones when compared with all other plant life forms (Figure 5C), indicating the dominance of perennial grasses.

There was no difference in the mean percentage composition of annual grasses across all rainfall zones, $\chi 2(2)=1.28$,p=0.53 (Figure 5C). No significant differences in mean percentages composition of annual grassed was observed between low and medium rainfall zones (p=0.323) as between low and high rainfall (p=0.355) and between medium and high rainfall zones (p=0.822). There was no significant difference in the mean composition of the sedges between low and medium rainfall zones, but there was significant differences in the mean percentage composition of sedges between low and high rainfall zones, and between medium and high rainfall zones. In the high rainfall zone the mean percentage composition of the sedges was highest. There were no significant differences in the mean percentage composition of herby and woody forb across all rainfall zones (Figure 5C). Similarly, the mean difference in percentage composition of geophytes was not significant across rainfall zones (Figure 5C).

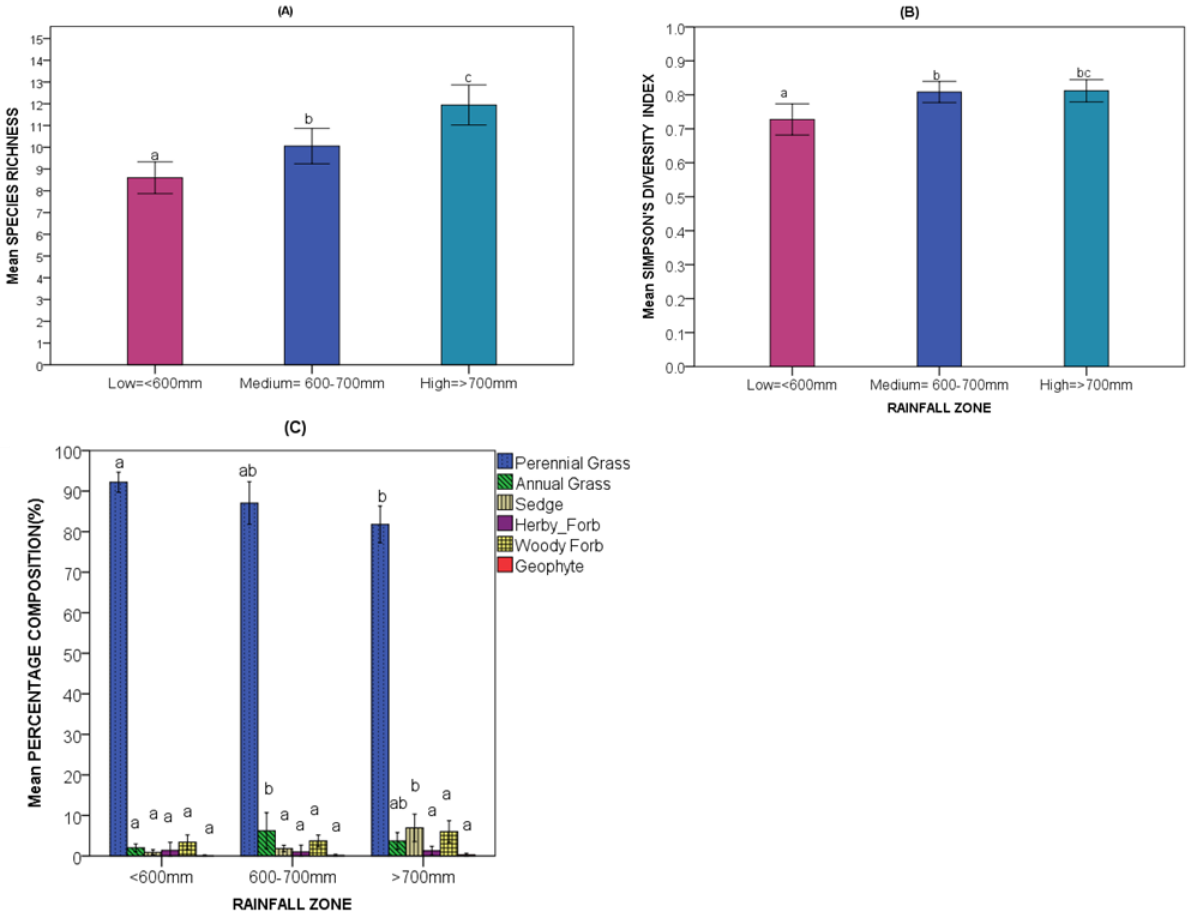


Figure 5: Mean (±SE) Species Richness (A), Simpson's Diversity Index (B) and Percentage Perennial Grass (C), between rainfall zones (Low, <600 mm; Medium,600-700 mm); High,>700 mm) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicate significant differences between rainfall zones.

3.1.2 Structure

The mean distance to perennial grass amongst the rainfall zones was not significantly different, $\chi 2(2)=5.2$, $p=0.07$. However, the mean distance to perennial grass increased with rainfall. There was significant difference between the low rainfall zone and high rainfall zone ($p=0.037$), but not between low rainfall and medium rainfall ($p=0.102$) or between medium and high rainfall zone ($p=0.429$) (Figure 6A). There was significant differences in the mean percentage grass basal cover across the rainfall zones, $F(2,53) = 5.78$, $p= 0.005$. Mean percentage grass basal cover was significantly higher in the low rainfall zone than in the high rainfall zone ($p=0.005$) (more than double), with that in the medium zone being intermediate between the two, and more variable.

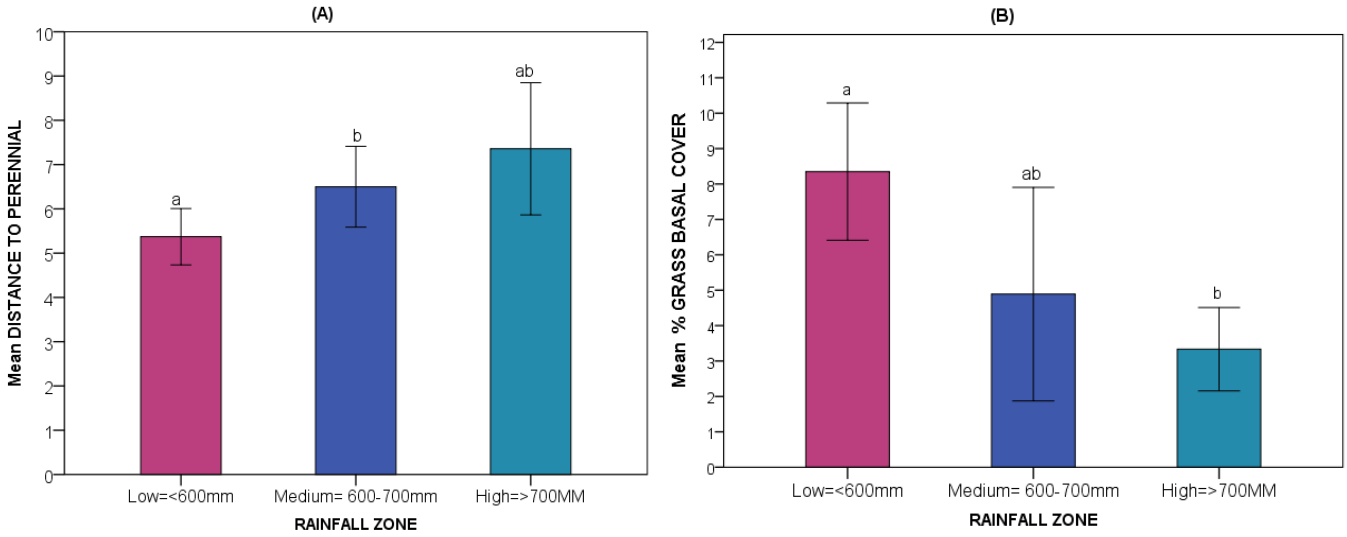


Figure 6: Mean (±SE) distance to perennial (A) and mean percentage basal cover (B) between rainfall zones (Low, <600 mm; Medium, 600-700 mm); High,>700mm in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicates significant differences between rainfall zones.

3.2 Composition and structure along a topographical gradient

3.2.1 Composition

The downslope catenal positions had 17% more species than upslope positions. The following species were found to be the top five most abundant species within the two topographical positions: *Digitaria eriantha*, *Heteropogon contortis*, *Panicum maximum*, *Urochloa mossambicensis* and *Aristida congesta* (Figure 7). The order of species abundance ranking was however different between the two catenal positions as depicted in Figure 7. *Digitaria eriantha* and *Panicum maximum* were the most abundant in the downslope and upslope catenal positions respectively. In the downslope catenal position the top five abundant species accounted for at least 52% of all species, whilst in the upslope catenal positions they accounted for 69% of all species. Therefore, the percentage of the top five abundant species was higher in the upslope than in the downslope catenal positions.

The decreaser species accounted for 54% of the top five abundant species and the increasers species 46% species in the downslope catenal positions. In the upslope catenal positions the decreasers species accounted for 64% of the top five abundant species composition whilst the increasers species

accounted for only 36% of composition. This shows that the decreaser species composition was higher in upslope positions than in the downslope catenal positions.

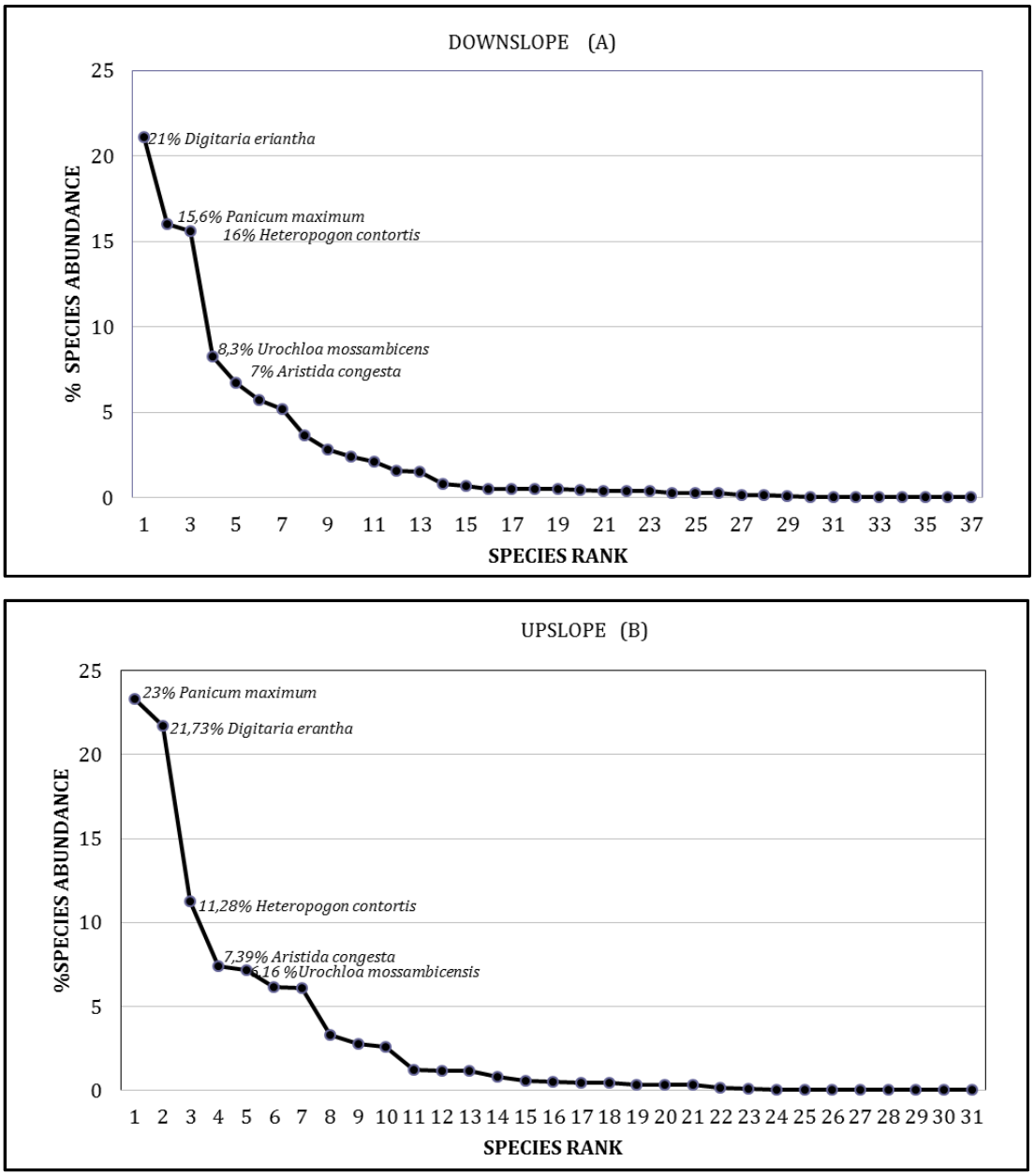


Figure 7: Species Abundance Ranking Curves for downslope (A) and Upslope (B) positions in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

The frequency distribution of all sampled species in upslope and downslope catenal position did not reveal any significant differences (Table 4). Similarly, the frequency distribution of five top common species, namely *Digitaria eriantha*, *Heteropogon contortis*, *Panicum maximum, Urochloa mossambicensis and Aristida congesta*, from upslope and downslope catenal positions was not different and therefore not significant (Table 4).

Table 4: Two sample Kolmogorov-Smirnov (KS) comparisons of all and top five common species composition distributions between topographical gradients in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Comparison	Measure	Kolmogorov-Smirnov(Ks) Test
		p-value
Downslope and Upslope	All Species	0.996
	Top-Five Common Species	0.819

There was no clear pattern on the species composition due to differences in topographical positions for both all sampled and top common five species data (Figure 8).

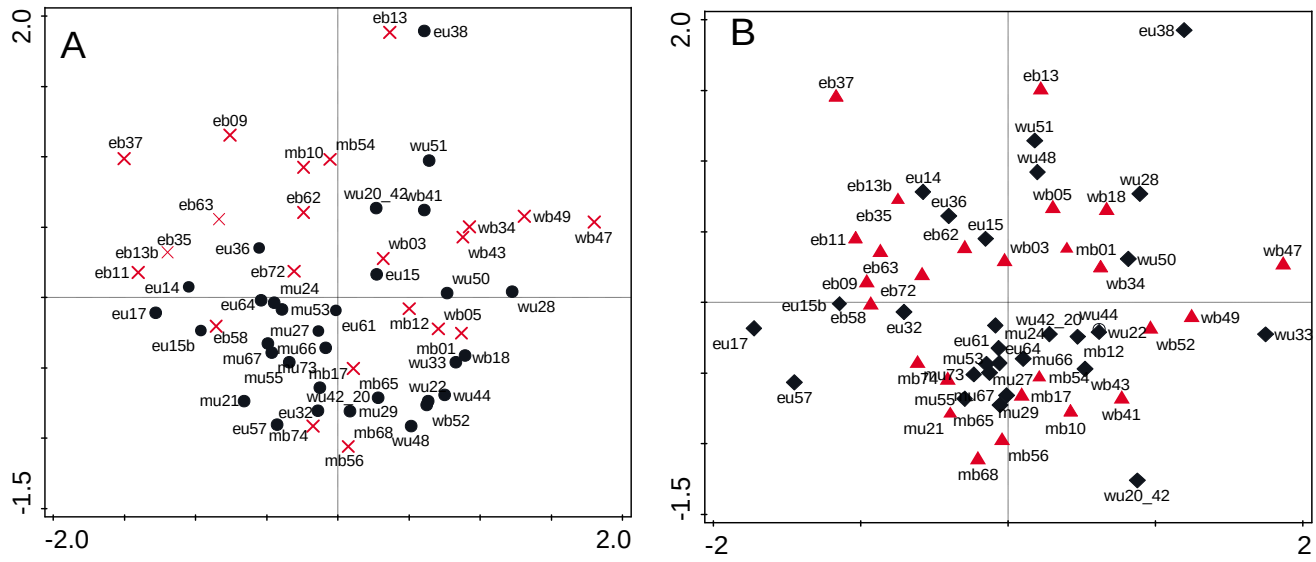


Figure 8: All species data (A) and Top Five (B) species composition per topographical gradient in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Key to environmental variables: **Graph A**-Downslope (×) Upslope (●), **Graph B**- Upslope (♦) downslope (▲**)**.

There was no significant difference in the means of species richness on the upslope and downslope positions, $t(54)=-0.18$, $p=0.86$ (Figure 9A). Similarly, the mean Simpson's Diversity Index between the downslope and upslope catenal positions was not significantly different, $t(54)=-0.48$, $p = 0.228$ (Figure 9B).

The mean percentage perennial grasses composition between the downslope and upslope catenal positions had no significant difference, U=323, p=0.26, (Figure 9C). Mean percent annual grass composition was significantly higher in the upslope sites, U=128, p<0.001, (Figure 9C). Mean sedge composition was significantly higher in the downslope position than in the upslope position. Similarly, the herby forbs composition was significant higher in the downslope position than in the upslope position. The upslope and downslope catenal positions were found to have no significant difference in the mean percentage composition of both mean woody forb and geophytes (Figure 9C).

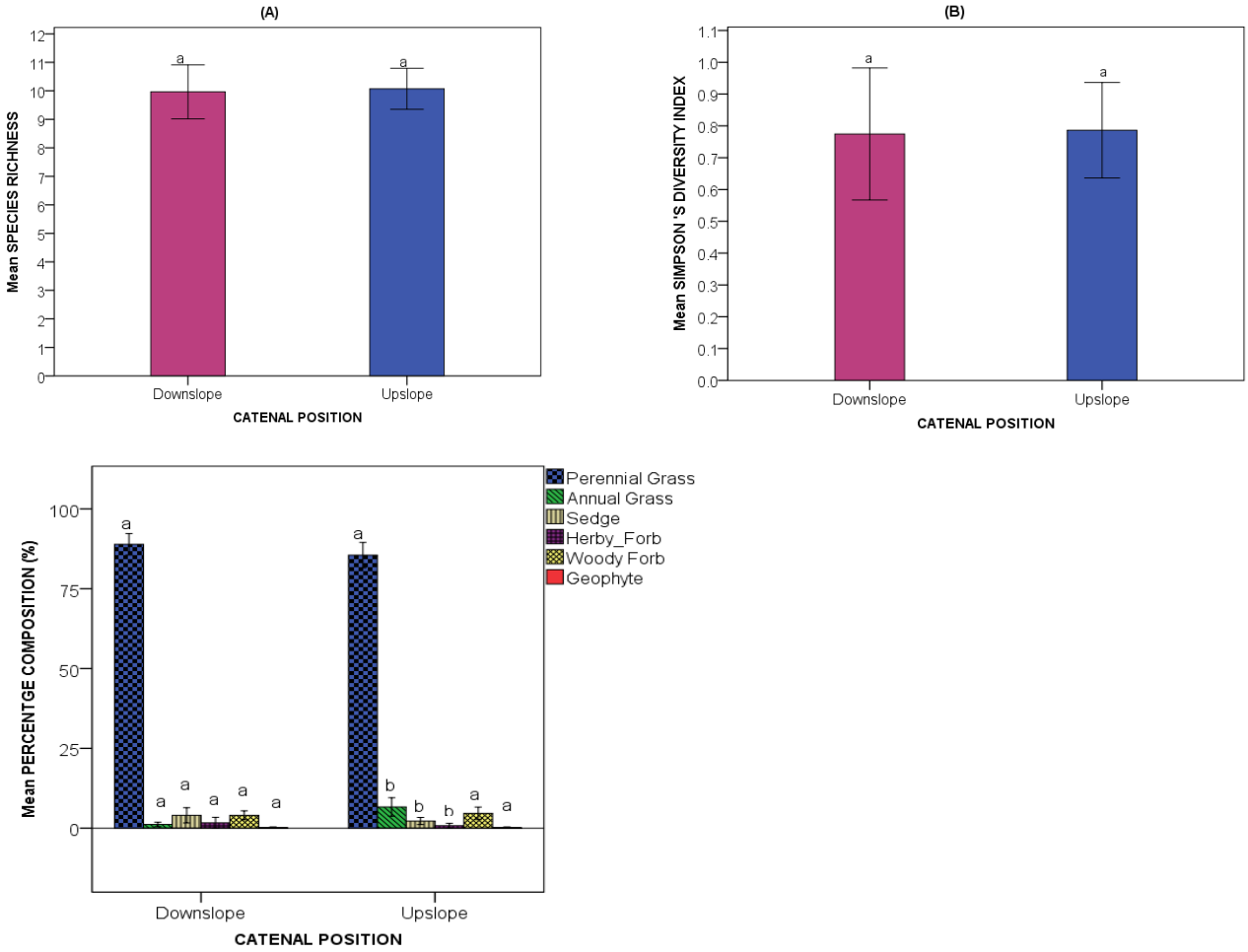


Figure 9: Mean (±SE) Species Richness (A), Simpson's Diversity Index (B), and Percentage Composition (C) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicate significant differences between catenal positions.

An independent-samples t-test was conducted to compare the means of distance to perennial of the catenal positions. There was no significant difference in the means of distance to perennial grass between the catenal positions, $t(54)$=-0.201, p =0.84 (Figure 10A). Similarly, there was no

significant difference in the means of grass basal cover between the upslope and downslope catenal positions, U= 375, p= 0.79, (Figure 10B).

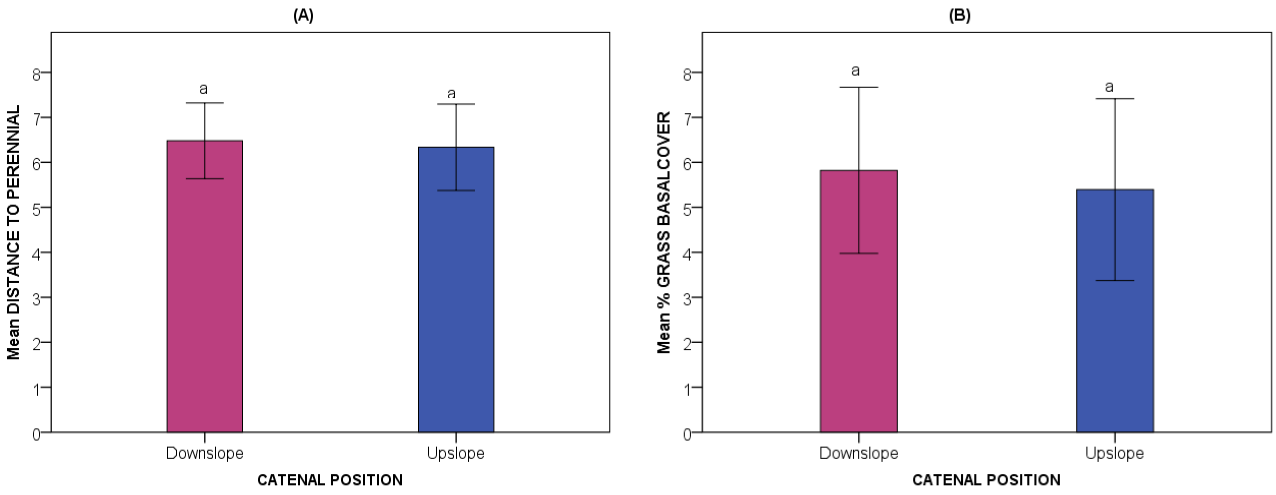


Figure 10: Mean (±SE) distance to perennial grass (A) and mean percentage grass basal cover (B) between Upslope and Downslope Catenal positions in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicate significant differences between catenal positions.

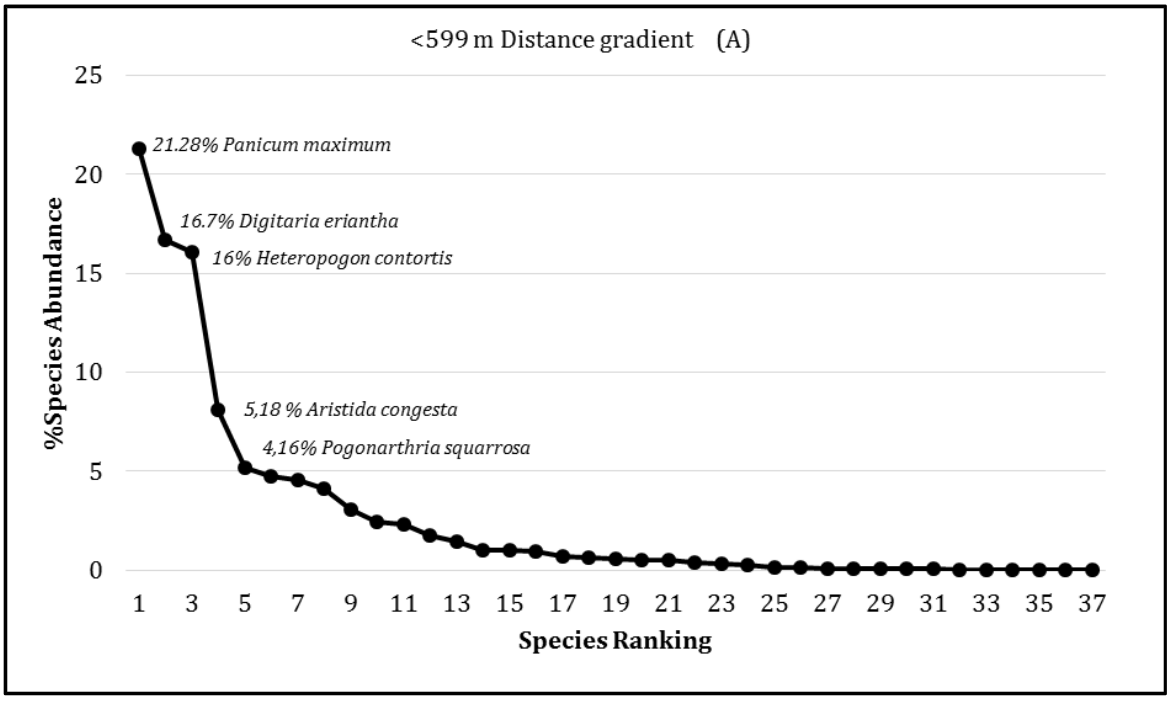
3.3 Composition and structure along a distance gradient

3.3.1 Composition

The plots nearest to the village (<599 m) had more species, than those between 600-1799 m and < 1800 m from the nearest village. The nearest areas to the village had 22% more species than the areas between 600-1799 m and >1800 m from the villages. The following species were found to be the top five abundant species within the three distance gradients: *Digitaria eriantha, Heteropogon contortis, Panicum maximum, Pogonarthria squarrosa and Aristida congesta* (Figure 11). The order of species abundance ranking was however different between three distance gradients positions as depicted in Figure 11 below. For instance, *Panicum maximum* was the most abundant with species ranking of 1 in the nearest plots to the villages whilst *Digitaria eriantha* had species ranking of 1 (one) in the mid- (600-1799 m) and furthest (<1800 m) disturbance gradients (Figure 11). The other species had different species ranking in different disturbance gradients. The average percentage of *Digitaria eriantha* in all zones indicated that it was the most abundant species whilst *Aristida congesta* was the least abundant species on average in all disturbances zones.

In the nearest zone, the top five abundant species accounted for at least 63% of all species, whilst in the mid-distance gradient the top five abundant species accounted for 72% of all species. In the >1800 m rainfall distance gradient the top five abundant species account for 62% of all species. The percentage of the top five abundant species was highest in the 600-1799 m distance gradient. The decreaser species accounted for 60% of the top five abundant species and the increasers species 40% species in the plots nearest to the villages. In the 600-1799 m distance gradient the decreaser species accounted for 63% of the top five abundant species, whilst in the >1800 m the decreaser species accounted for 66% of the top five abundant species. This shows that the decreaser species abundance increased with a disturbance gradient further away from the villages.

When categorizing the species in terms of decreaser and increaser species the following applies, of the top five abundant species the percentage of palatable decreaser species, *Panicum maximum* and *Digitaria eriantha* closer (38%) were more than of the unpalatable species, *Heteropogon Contortis*, *Pogonarthia squarossa* and *Aristida congesta* (25,3%). The composition of decreaser species accounted for 60% of the top five abundant species and the increasers species 40% species in the plots nearest to the villages. In the 600-1799 m distance gradient the decreaser species accounted for 63% of the top five abundant species, whilst in the >1800 m the decreaser species accounted for 66% of the top five abundant species.



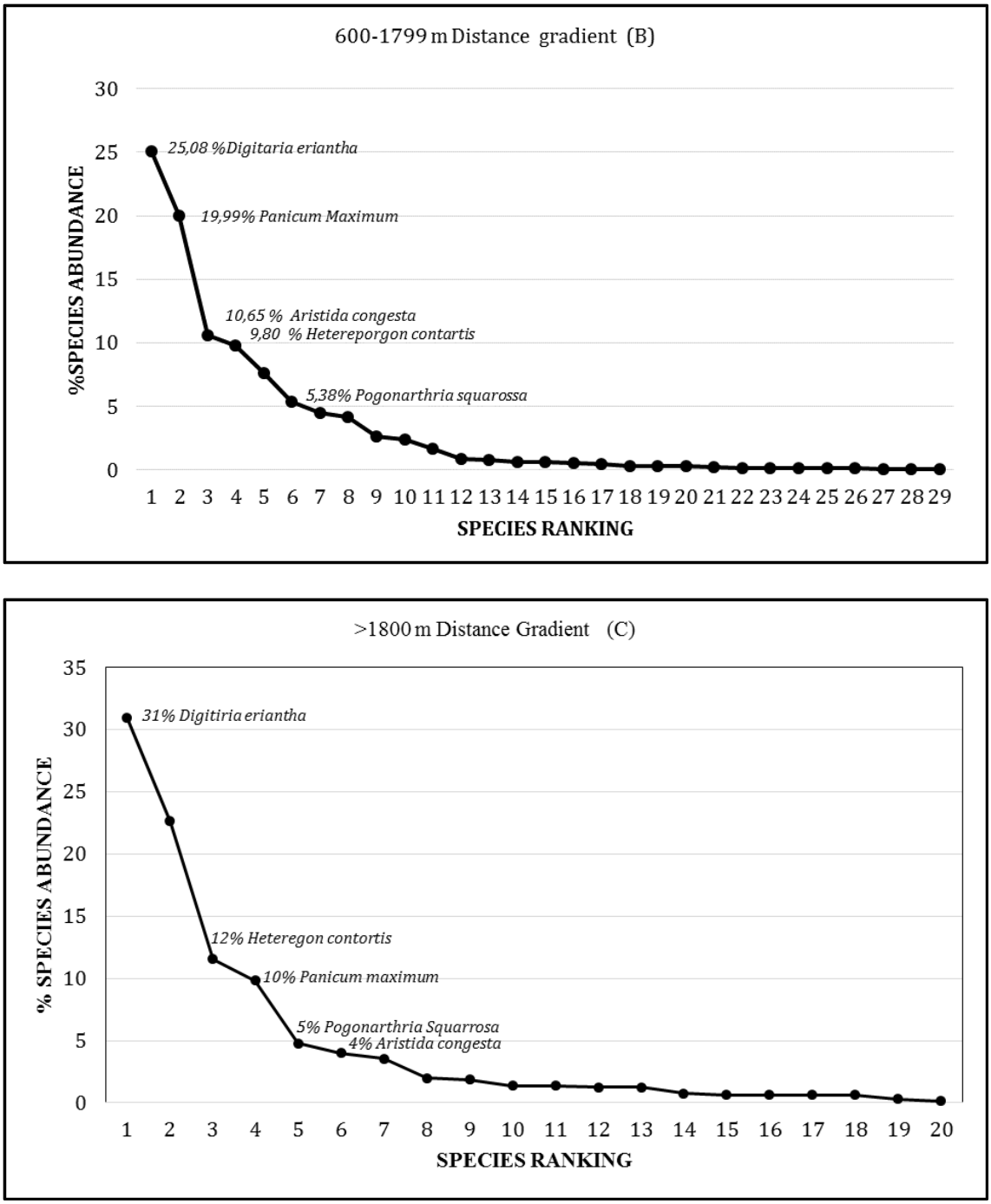


Figure 11: Species Abundance Ranking Curves for distance to village (A) <599 m, (B) 600-1799 m and (C) >1800 m) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

There was overall significant differences in the mean species richness in the distance gradients, $F(2;53)=6.26$, $p=0.004$. However, the mean species richness was significantly higher at 0-599 m from the village than at 600-1799 m and >1800 m from the village, (Figure 12A). It was significantly different between 0-599 m and 600-1799 m ($p=0.05$) and between 0-599 m and >1800m ($p=0.007$) but not between 600-1799 m and >1800 m ($p=0.347$). There was no significant difference in the

means of Simpson's Diversity Index across all distance gradients, $\chi 2(2)=1.13$, $p=0.57$ (Figure 12B). Across all distance gradients the mean percentages of perennial grasses was not significantly different, $\chi 2(2)=3.93$, $p=0.14$. Similarly, there difference in the mean percentages of the annual grasses did not differ significantly in all distance gradients, $\chi 2(2)=1.43$, $p=0.49$. The mean percentages of sedges, herby forbs, woody forbs and geophytes were not significantly different. The perennial grasses had the highest percentage composition in all rainfall zones when compared to annual grasses and other plant life forms (Figure 12C).

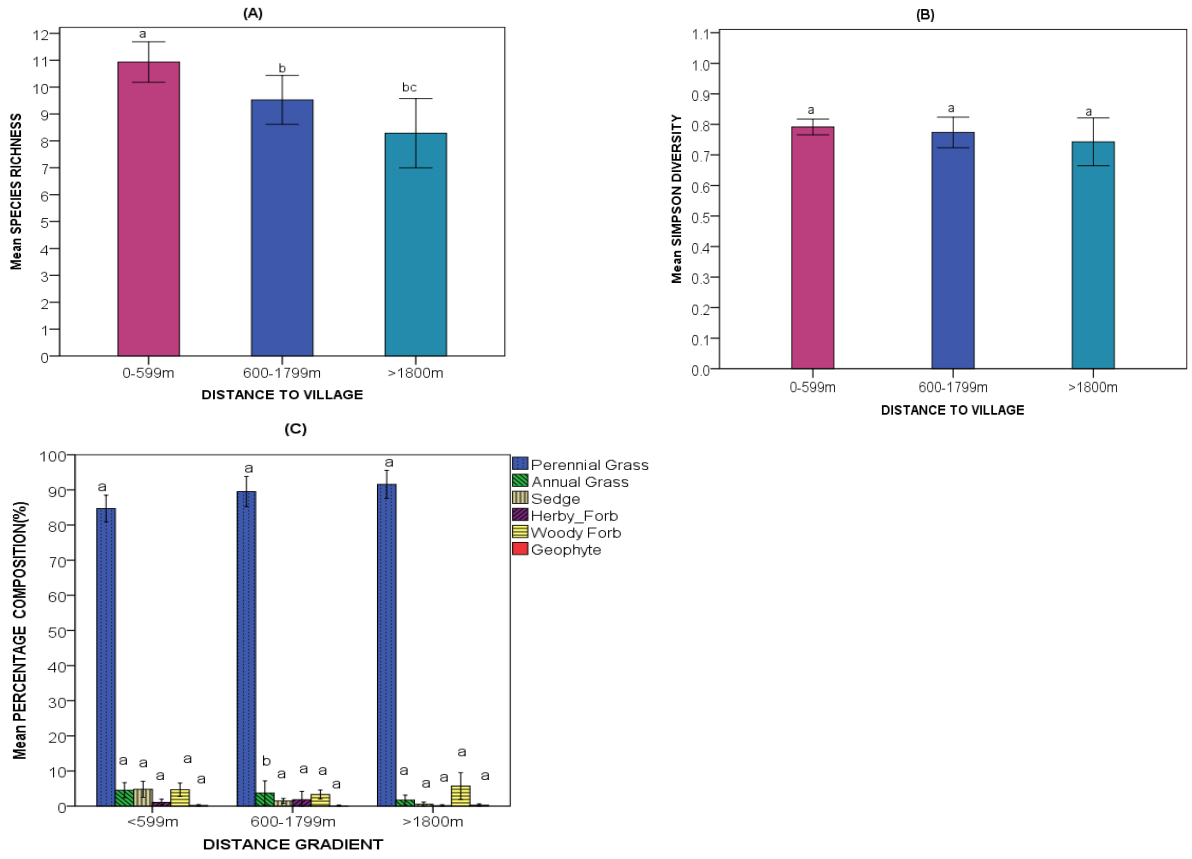


Figure 12: Mean (±SE) Species Richness (A), Simpson's Diversity Index (B), Percentage Composition (Perennial Grass, Annual grasses, Sedge, Herby Forb, Woody Forb and Geophyte) (C) among distance gradients of (0-599m; 600-1799; >1800m) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicate significant differences between distance gradients.

In addition to the categorical analyses, linear regression analysis was carried out to determine the extent to which distance to village can individually predict species richness, Simpson's Diversity Index and perennial grass percentage (Figure 13). There was a significant negative correlation between species richness and distance to village ($p<0.05$), although the predictive power was low

due to high variation in the data (R^2=0.131). There was no significant linear relationship between distance to perennial grass and either Simpson's Diversity Index and percentage perennial (Figure 13).

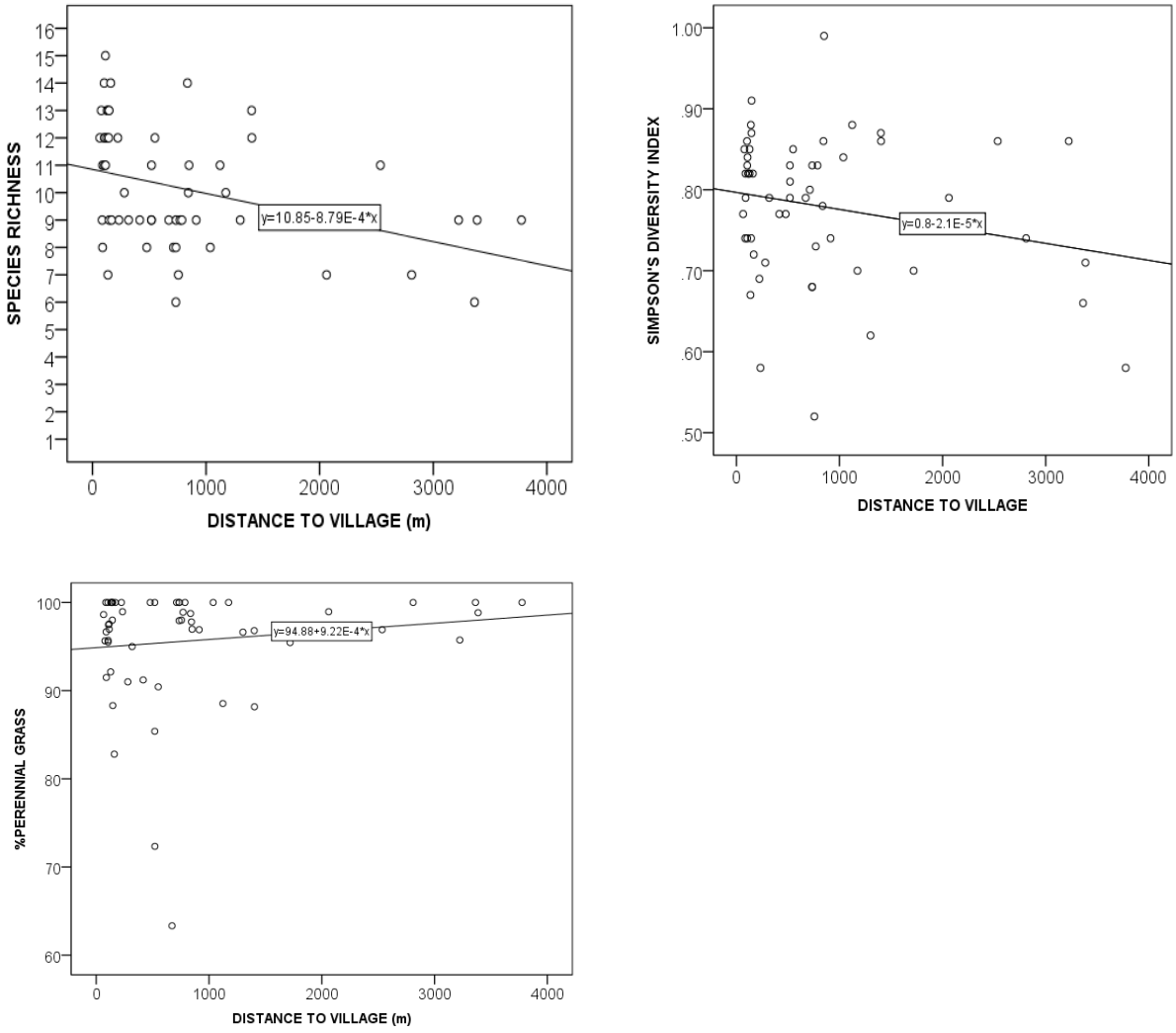


Figure 13: Scatter plots and the corresponding regression lines and regression equations for the relationship between the dependent variables, Species Richness, Simpson 's Diversity Index and the independent variable Distance to village (m) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

3.3.2 Structure

The mean distance to perennial grass was higher in the plots closest to the villages than the other two distance zones, but this difference was not significant, $\chi 2(2) = 1.34$, $p = 0.51$ (Figure 14A). Mean basal cover was significantly higher in the plots far from village than at the nearest and mid plots, $\chi 2(2) = 9.7$, $p = 0.008$ (Figure 14B). However, the difference in the mean basal cover was significant

between 0-599 m and >1800 m (p=0.007) and between 0-599 m and 600-1799 m (p=0.03) but not between 600-1799m and 1 800 m (p=0.15) distance gradients.

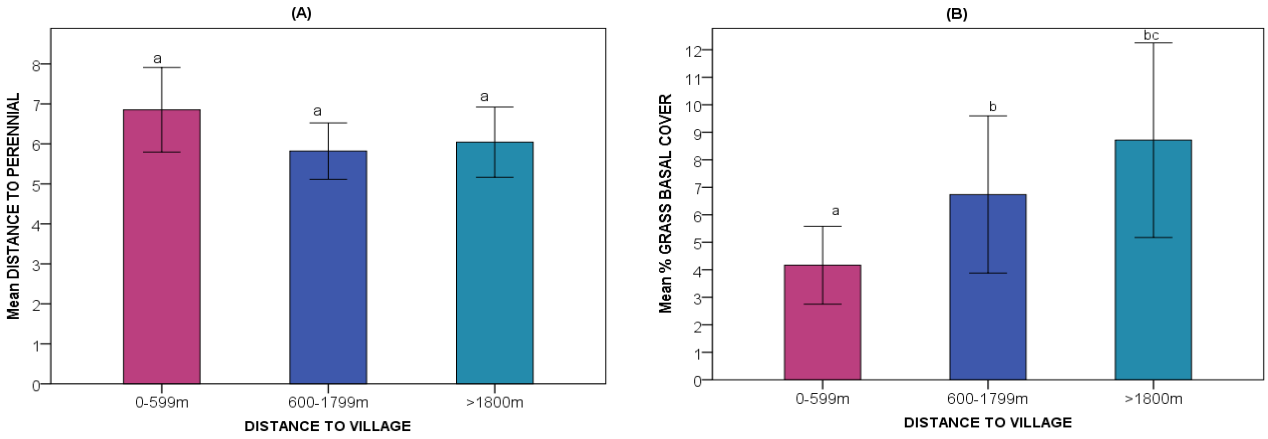


Figure 14: Mean (±SE) distance to perennial grass (A) and Grass basal cover (B) between distance gradients of (0-599m); 600-1799; >1800m**)** in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. Different letters indicate significant differences between distance gradients.

A simple linear regression was also carried out to determine the extent to which distance to village can individually predict distance to perennial grass and grass basal cover (Figure 15). There was no significant relationship between mean distance to perennial grass and distance to village. However, there was significant relationship between grass basal cover and distance to village ($F=9.297$, $p<0.05$).

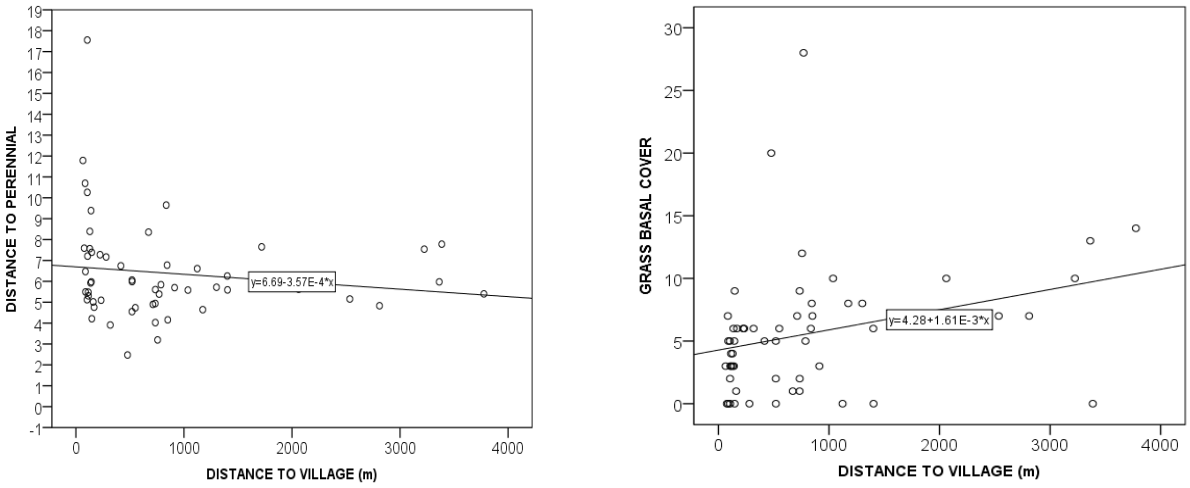


Figure 15: Scatter plots and the corresponding regression lines and regression equations for the relationship between the dependent variables (distance to perennial grass, grass basal cover) and independent variable Distance to village (m) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

3.4 Combined effect of rainfall, topographical and disturbance gradients on the herbaceous composition and structure.

3.4.1 Composition

The Canonical Correspondence Analysis (CCA) was done to determine the relationship between a combination of environmental variables and species composition (Figure 16). The results from CCA applied to the all environmental variables considered and 44 species indicated that Axis 1 accounts for 7% of the observed variation in vegetation, whereas Axis 2 accounts for 5.29%, whilst Axes 3 and 4 account for 3,22%. All cumulative explained variation is 17.08% (Table 5). The permutation test results on all axes is F=2.2 and significant p value <0.002 for all explanatory variables.

Table 5: Summary results of the canonical correspondence analysis (CCA) for 56 plots sampled in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.1767	0.1335	0.0813	0.0395
Explained variation (cumulative)	7.00	12.29	15.51	17.08
Pseudo-canonical correlation	0.8933	0.7972	0.7515	0.6452
Explained fitted variation (cumulative	39.06	68.55	86.52	95.25

The species that were highly associated with high rainfall zone were amongst others *Sporobolus pyramidalis*, *Cynodon dactylon*, *Hyperthelia dissolute*, *Hyperrhenia filipendula and Eragrostis spp (unknown species)* (Figure 16) and this species were also intermediately associated with distance gradients of 0-599 m than with 600-1799 m and >1800 m. *Perotis patens*, *Trichneura grandiglumis*, *Michcocloa caffra* were strongly associated with upslope sites in the mesic rainfall zones. *Brachiaria deflexa*, *Elionorus muticus*, *Themeda triandra*, *Eragrostis superba*, *Eragrostis trichophora* were strongly associated with downslope catenal position, low rainfall and distance gradients of >1800m. However, the degree of association of individual species with particular environmental gradients were varied.

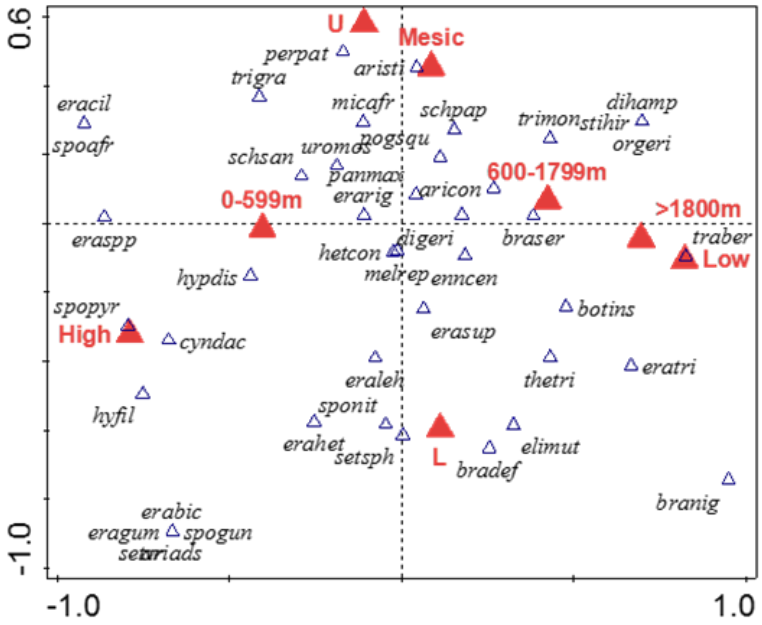


Figure 16: Canonical correspondence analysis (CCA) ordination diagram depicting the relationship of herbaceous species (Δ) abundance and environmental factors (▲) (56 plots 2012 dataset) in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa. **Key to environmental variables:** L – downslope topographical position; U – Upslope topographical position; Low – Low rainfall zone; Mesic – Medium rainfall zone; High – High rainfall zone. Full names of plants are available in Appendix 1.

3.4.2 Structure

The interaction effect of distance to perennial grass between catenal position and distance, catenal position and rainfall zone, and distance and rainfall zone was found to be not significant. However, there was a significant interaction effect between rainfall, topographical gradients and distance gradient on the distance to perennial grass (Table 6). The interaction effect on basal cover between catenal position and distance, catenal position and rainfall zone, and distance and rainfall zone were

all found to be not significant. The interaction effect of the rainfall, topography and distance gradients on the structure of herbaceous vegetation on the grass basal cover grass was found to be not significant (Table 7). However, it is possible that with a large sample it could have been significant.

Table 6: Factorial three way-ANOVA results for comparison of influence of rainfall zone, topographical position and distance gradient and their interaction effect on the structure of herbaceous vegetation as denoted by distance to perennial grass in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Measure	**Statistics**	**Topographical *Distance**	**Topographical *Rainfall**	**Distance* Rainfall**	**Rainfall* Topography *Distance Interaction**
Distance to Perennial	P-value	0.903	0.502	0.539	**0.037**
	F	0.102	0.700	0.627	4.657
	df	2	2	2	1
	Mean	0.78	0.78	0.75	0.76
	S.E	0.22	0.18	0.025	0.21

Note: Significant values in bold letters, ($p<0.05$)

Table 7: Factorial three way-ANOVA results for comparison of influence of rainfall zone, topographical position and distance gradient and their interaction effect on the structure of herbaceous vegetation as denoted by basal cover in communal rangelands of Bushbuckridge, Mpumalanga Province in South Africa.

Measure	**Statistics**	**Topographical *Distance**	**Topographical *Rainfall**	**Distance* Rainfall**	**Rainfall* Topography *Distance Interaction**
Grass Basal Cover	P-value	0.821	0.383	0.751	0.083
	F	0.198	0.981	0.289	3.148
	df	2	2	2	1
	Mean	6.32	5.51	5.55	5.91
	S.E	0.70	0.58	0.91	0.71

Note: Significant values in bold letters, ($p<0.05$)

CHAPTER 4

4 DISCUSSION

4.1 Composition and structure along a rainfall gradient

4.1.1 Composition

The relationship between long-term mean annual precipitation and species richness of herbaceous vegetation was determined across a rainfall gradient. Consistent with the expectation of this study it was established that there was an increase in the abundance of species from low to higher rainfall zone. It was found that the species abundance curve indicated that the medium rainfall zone had the lowest total species abundance and highest in the higher mean annual rainfall zone. Rainfall as a proxy for moisture availability is one of the factors that has an influence on the quality and quantity of herbaceous vegetation (Hopkins, 2000; Pandey & Singh, 1992). The availability of water or moisture in the soil profile is influenced by the frequency and seasonal distribution of rainfall, thereby strongly affecting arid vegetation dynamics and composition (Comstock & Ehleringer, 1992; Ojima *et al.*, 1993; Graetz *et al.*, 1988). Therefore, the variation in precipitation is manifested in the degree of soil moisture available, which is accepted as a driver of vegetation dynamics (Jones *et al.*, 2016).

Various studies have demonstrated positive response of species richness to rainfall. In the study by Shackleton (2000), in the Bushbuckridge area it was established that there was a similar correlation between mean annual rainfall and species richness of grass species. Additionally, there have been further studies that have been done in different environments which supported such positive relationship. For instance, Adler and Levine (2007) showed a positive effect of rainfall on species richness. This positive relationship could be attributed to indirect effects of rainfall on multiple biotic and abiotic variables (Adler & Levine, 2007). As mean annual precipitation increases so is moisture availability given that rainfall is substitute for moisture availability, therefore as resources become more available it creates a more conducive environment that enables survival of greater number of species with resultant increase in species richness (Pausis & Austin, 2001). A study by Kirkman *et al.* (2001), also highlighted the importance of moisture as a limiting resource having an effect on species richness. However, the local drivers of species richness may differ from one area to another. Also other factors other than rainfall and moisture may drive species richness as was demonstrated by Maestre (2004) in a study in the Mediterranean semi-arid steppes. Steenekamp and Bosch (1993) in their study in determining different reactions of species

to a rainfall gradient determined that certain herbaceous species were more abundant in one rainfall zone than in the other two zones sampled. In another a study by Hochrasster *et al.* (2002), it was highlighted of the increase in perennial grass species richness due to an increase in precipitation. Perennial grasses are generally said to have more advantage than annual grasses due to the fact that they are deeper rooted than annual grass species and therefore able to access deeper soil moisture than annual grasses (Schenk & Jackson, 2002), whilst other species were not reactive to any rainfall gradient.

Overall, the mean Simpson's Diversity Index was highest in the high rainfall zone compared to the low and medium zones investigated. The upward trend also demonstrate the positive relationship between the species richness and species diversity. As mean annual precipitation increase there tends to be an increase in moisture availability, thereby leading to increase in resources (water and nutrients) increase and resulting in more species that can survive and also resulting in species richness rising (Pausis & Austin, 2001), with resultant corresponding increase in species diversity. The increase in the mean value of Simpson's Diversity Index signifies an increase in herbaceous species diversity and decrease in species dominance.

The herbaceous layer was heavily dominated by perennial grasses in all rainfall zones, with the low rainfall zone having the highest mean percentage perennial grasses composition and the highest rainfall zone having the lowest mean percentage perennial grass composition. On the other hand, the composition of annual grasses was lower in the low rainfall zone and highest in the medium rainfall zone and intermediate on the high rainfall zone. It was established that compared to other plant life forms sampled, perennial grasses were the most dominant life form in all rainfall zones. The top five abundant species in all rainfall zones were dominated by a mixture of both palatable perennial species *(Panicum maximum*, *Digitaria eriantha*) and unpalatable perennial grass species, *Heteropogon contortis*, *Urochloa mossambicensis* and *Pogonarthria squarrosa*. Among the top five perennial species, *Panicum maximum*, a palatable perennial grass was the dominant in all rainfall zones whilst *Pogonarthria squarrosa* was the least abundant species in all rainfall zones. Perennial grasses and woody plants dominate the vegetation structure in the semi-arid savanna (Scholes & Archer, 1997). In another a study by Hochrasster *et al.* (2002), it was highlighted of the findings made in other studies indicating an increase in perennial grass species richness with an increase in precipitation. Other species were not reactive in any rainfall zone, however the advantage that perennial grasses have over annual grasses is consistent with Walter (1991) niche model as they are deep rooted as compared to annual grasses. This may give more

credence to the niche separation model as proposed by Walter (1971), this time restricted to perennial and annual grasses. The dominance of perennial grasses over other plant life forms in this communal land is typical of savanna vegetation. In southern Africa's semi-arid savanna, the composition of perennial and annual grasses is regulated by the degree of availability of water, and drought conditions can have an effect on the decrease in perennial grasses and increase of annual (Hochrasster *et al.*, 2002). However, perennial grasses have advantage over annual grasses in that they are able to use water throughout the year. Under heavy rainfall *Panicum maximum* (Guinea grass), a palatable grass performs better under rotational grazing (Aganga & Tshwenyane, 2004). The degree of disturbance due to human activity or specifically due to grazing in the communal lands located in the different rainfall zone could account to difference in the perennial grasses and other life form composition in rainfall zones.

4.1.2 Structure

The high rainfall zone had higher mean distance to perennial grass than in the low rainfall zone. This means that tuft density was lower in the higher rainfall zone. This is contrary to the expectation of this study. Buiternwerf e*t al.* (2011) investigated effect of rainfall on basal cover due to rainfall and found the positive effect of rainfall on basal cover. This implied an increase in basal cover as the spaces between the tufts are reduced which in effect reduced the erosion potential. In another study, Novellie and Strydom (1987) confirmed positive effect of rainfall on tuft density by reporting on an increase in tuft density with an increase in in rainfall over a long period of monitoring thereby confirming effect of rainfall in grass basal cover.

The mean percentage grass basal cover was higher in low rainfall zones and lower in high rainfall zones. Buiternwerf e*t al.* (2011) found in their investigation of positive effect of rainfall on basal cover. Derner *et al.* (2009) in a different environment reported on the increase in basal cover in the short grass steppe and sagebush grassland. It is clear that other studies found the positive effect that rainfall has on basal cover and tuft density and therefore it was postulated in this study that higher rainfall would result in reduced inter-tuft density compared to low and medium rainfall areas. However, there might be other factors that might have contributed to the results in individual rainfall zones as other variables are involved in vegetation composition and structure dynamics that have not been the subject of this study. This study was also focused only on single year data other than multi-year data and therefore might not reveal adequate trend in this regard. It is possible that more information could have been provided should quadrats method have been used noting a study

by Stohlgren *et al*. (1998) on comparative study on sampling methods, which indicated that with more area sampled the quadrats method could have provided more information.

4.2 Composition and structure along topographical gradient.

4.2.1 Composition

In this study, it was established that in the upslope and downslope catenal positions the mean species richness was not significantly different, which was contrary to what was expected. It was expected that the downslope catenal positions would have higher species richness than upslope catenal position because due to availability of nutrients which are carried by water to downslope compared to upslope area (Mlot, 1990), thereby creating conditions conducive for vegetation growth due to eutrophic soil on the bottomslope. A study by Fujita *et al.* (2009) highlighted the positive effect of bottomlands on the species richness and negative effect on the upper slope. The downslope positions are expected to have higher soil moisture and nutrients. This can be attributed to the moisture availability and surface mobilization of soil matter and geochemical solutions and their eventual accumulation in depressions and thereby creating favourable conditions in the downslope areas when compared to vegetation growth in upslope positions (Solon *et al.*, 2006*).* The site specific conditions or influences such as soil, hydrogeological and grazing could have played a role in the species richness being not as much different on the upslope and downslope positions.

Furthermore, it was established that contrary to what was observed in regards to effect of rainfall in distribution of species, there was no difference in pattern on species frequency distribution due to catenal differences. This was consistent with the results of Kolmogorov-smirnof test which indicated that there was no significant difference in the distribution of species between the two catenal positions. Species abundance curves revealed that there were more species on downslope positions than upslope positions. However, mean Simpson's Diversity Index was higher on the downslope position than on the upslope catenal position. The downslope position's increased Simpson's Diversity Index can be attributed to availability of nutrients and water compared to the upslope position. Huston (1979) and Kondoh (2001) cited by Carlson (2011) highlighted that the difference in diversity response between sites may be caused by productivity differences or by differences in grazing frequency which lead to greater differences in species richness as a result of higher levels of disturbance at sites with greater productivity. The downslope areas are expected to be of high productivity due to resource availability.

The composition of perennial grasses between the upslope and downslope catenal position was not significantly different. The proportion of perennial grasses was more than that of annual grasses and other life forms sampled. It was expected that the percentage of grasses would be higher on the downslope due to resource availability on the downslope as a result of mobilization of nutrients and flow of water. However, it was established that the downslope catenal positions had 17% more top five abundant grass species than upslope positions. In a study by Parsons *et al.* (2000), it was established that the downslope catenal position had more species (>30%) than upslope positions. *Aristida congesta*, an annual grass species was present as one of the top five species together with perennial grasses, *Digitaria eriantha, Heteropogon contortis, Panicum maximum and Urochloa mossambicensis. Digitaria eriantha* and *Panicum maximum* were the most abundant in the downslope and upslope catenal positions respectively. The percentage of the top five abundant species was higher in the upslope than in the downslope catenal positions. With the exception of *A.congesta*, an unpalatable grass, the other four species as mentioned above were palatable. Consistent with what was reported in Parsons *et al. (*1997) an annual species, *Aristida congesta* was found to be abundant species in the communal area. The decreaser species accounted for 54% of the top five abundant species and the increasers species 46% species in the downslope catenal positions.

In the upslope catenal positions the decreasers species accounted for 64% of the top five abundant species composition whilst the increasers species accounted for only 36% of composition. Evidently, the decreaser species composition was higher in upslope positions than in the downslope catenal positions. Contrariwise, the increasers grass species were dominant in the downslope catenal positions. The dominance of decreasers is indicative of a veld that is being moderately utilized by grazing animals, whilst the dominance of increasers suggests overutilization by grazing animals (Trollope *et al*., 1989). Therefore, the downslope catenal positions are possibly moderately utilized whilst the upslope catenal positions where overutilised. The resource availability (water and nutrients) on the downslope catenal position could also be assisting in ensuring regrowth of grass species when compared to the upslope position which might take longer time to recover due to absence of conducive resource conditions.

4.2.2 Structure

It was established in this study that the distance to perennial grass tuft was not different between the upslope and downslope positions. Distance to perennial grass tuft is a proxy for density of perennial tufts, therefore there was no difference in the density of perennial grass tufts between

the upslope and downslope catenal positions. Similarly, no differences could be detected between the mean percentage grass basal cover between the upslope and downslope catenal positions which is contrary to what was hypothesized. Due to the impact that soil catena has on the vegetation structure some difference was expected due to water and nutrients mobilization to downslope areas therefore providing required resources for growth. The findings of the study are contrary to what was found by Parsons *et al.* (1997), who established that the mean percentage of grass basal cover was highest in the bottomlands than in the uplands. The no differences in the structural measures of distance to perennial grass and grass basal cover could be attributed to other determinants of vegetation that played a role in the savanna communal lands like grazing. No determination was made in the extent to which factors like grazing could play in the upslope and downslope areas given. However, it could be postulated that the reason why there was no difference in the structural measures studied is that the bottomlands could have been grazed in such a way that resulted in the perennial tuft density and basal cover being reduced to equivalents levels as in the uplands. It is to be noted that influence of proximity to the water courses or watering points were not explored as it could have assisted in further explaining the effect of grazing on bottomlands when compared with the uplands.

4.3 Composition and structure along a disturbance gradient.

4.3.1 Composition

The study on the herbaceous vegetation composition occurred on the disturbance gradient (grazing intensity) of 0-599 m, 600-1799 m and >1800 m from the nearest village. It was established in this study that closest plots to villages had 22% more species than the plots between 600-1799m and 1800m from the villages. Overall, species abundance increased with decreasing distance from villages. The results of the study show signs of impact of grazing on palatable decreaser species indicating impact of grazing around the communal areas with a decrease in percentage of palatable grasses as compared to plots 600-1700 m and 1800 m. As per Shackleton *et al.* (2001), the communal areas in South Africa are known to have high human population and usually high stocking rate, which ultimately results in a decrease in palatable grazing species due to overgrazing and such areas being degraded (Shackleton *et al*., 2001). Furthermore, Owen-Smith (1999) and Joubert (1997) highlighted that some signs of land degradation amongst other indicators is eventual domination by unpalatable species after loss of perennial grasses in particular near boreholes or settlements. The reduction in perennial grasses ultimately also make way for annual grasses. On continued grazing desirable plants disappear, resulting in an increase in botanical

composition of the invader species and bare ground (Ünal *et al.*, 2011), and susceptibility of areas to erosion. In this case the percentage composition of decreasers species decreased with increasing grazing pressure.

The species richness was found to be higher near the villages (0-599 m), than in the 600-1799 m and >1800 m distance gradients from village. The grazing areas nearer to the villages are more likely to be heavily grazed than those that are further away which are lightly grazed (Twine *et al.*, 2009). A study by Tegegn *et al.* (2011) established that in the highly and moderately grazed site the species richness was significantly higher, while the species richness was also higher in lightly grazed sites than in severely grazed sites. Pandey and Singh (1992) reported that in the grazed savanna there was a higher herbaceous species richness when compared to ungrazed savannas. Van Coller *et al.* (2013) also found that highest species richness was associated with areas that have been grazed and had highest plant community diversity. This further highlighted the roles that herbivory has on species richness. Van Coller *et al.* (2013) citing Bakker *et al.* (2003) reasoned that herbivory by grazing animals results in vegetation patchiness, and this is said to encourage the coexistence of different species resulting in higher species richness. This support the previous findings that grazed areas are likely to have more species richness than less grazed areas. Shackleton (1994) highlighted on various studies that found a positive effect, or no effect of human induced disturbance on rural areas on species richness relative to less impacted areas. In grazed areas, trampling by animals such as sheep, cattle and horses tends to create gaps in vegetation due to death of established individuals resulting in opportunities for seedling recruitment (Gaujor *et al.*, 2012).

The studies highlighted above supports the findings made in this study. It must be noted that different studies may reveal differences in the temporal and spatial patterns of grazing and this may therefore explain the observed differences in vegetation responses (Busso *et al.*, 2004). A study by Gebremeskel and Pieterse (2015) on the effect of water points on botanical composition on semi-arid rangeland in Ethiopia indicated an increase in species abundance in points nearer to the water points than points further away. Exclusion of areas from grazing had been shown to also lead to a decrease in species richness. In these study this areas are represented by areas further from the settlements, thereby underlying the contribution that grazing has on species richness consistent with the study by Deng *et al.* (2013), where effect of different grazing intensities was investigated. In this study the different grazing intensities can be represented by the different distance gradients with the furthest gradient representing low grazing intensity and the nearest

higher grazing intensity, while the mid areas represent moderate grazing intensities. Though this shows an increase in species richness, Deng *et al.* (2013) showed that species richness peaks up to a point in moderate grazing beyond which then a decrease is initiated. In a different study in the Kalahari by Rutherford and Powrie (2013) it was established that a decline in species richness was due to increased grazing beyond substrate stability of the normally vegetated, fixed dunes. This suggest that though grazing does increase species richness there is a grazing pressure point beyond which species richness decrease.

However, it is important to understand the grazing associated mechanisms which trigger an increase in species richness. The composition of plant species and productivity of the vegetation are to a greater extent influenced by animal species, intensity of grazing and edaphic factors. In a study by Busso *et al.* (2004), various reasons were advanced that attributed the increase in species to have been due to grazing. Grazing was found to generate habitat patches that resulted in habitat heterogeneity, together with other non-grazing activities these created variety of conditions that were conducive to colonization by other species. It is important to know the extent to which the herbaceous layer can be changed when affected by grazing pressure in order to understand its resilience (Harrison & Shackleton, 1999).

The Simpson's Diversity Index was not significantly different among the distance (disturbance) gradients. The hypothesis in this study, that the higher Simpson's Diversity Index will be found in areas further from the villages than areas closer to the village which was contrary to the results realized. It is speculated that sample size could also have played some role as it was found that most of the samples where from distance gradients closer to the villages as compared to less samples from distance of between >1800 m. The general problem posed by small sample size is decreased predictive ability and increased margin of error. Therefore, the small size of the data from distance greater than 1800 m could have resulted in some bias that was not representation of actual situation. It is possible that a large sample size could have resulted in a different outcome. It is commonly accepted that species richness and diversity have positive relationship. Higher grazing pressure affect the species diversity and composition by increasing the loss of the dominant species thereby creating conditions favourable to colonization by less competitive, but grazing tolerant plant species (Sternberg *et al*., 2000).

Other studies have reported that an increase or decrease in plant species diversity can be attributed to selective and non-selective grazing or soil disturbances (Busso, 2004). The Intermediate Disturbance Hypothesis (IDH) holds that with varying levels of environmental, natural and anthropogenic disturbances species diversity is maximized, because less competitive, disturbance-tolerant species and competitively dominant, disturbance-sensitive species coexist when disturbances are neither too rare nor too frequent (Yuan *et al*., 2016). In the study by Riki and Fakhire (2014) relating to effect of different levels of grazing it was found that the highest diversity was found under light grazing conditions. In this study there was no difference in the diversity measures in across different distance gradients, however the smaller sample size used in the greater than 1800 m distance gradient could have played a role in not giving a more accurate outcome.

There was no significant difference in the percentage of perennial grass along the disturbance gradients. The perennial grasses were consistently dominant over the annual grasses along the disturbance gradients. Walker *et al.* (1981) in Harrison and Shackleton (1999) suggested that many perennial grasses, including many early successional species, can withstand intense grazing due to a significant proportion of their biomass being underground, based on previous empirical root studies. In this study the actual stocking rate and related management aspects along the distance gradient is unknown which would have assisted in determining their influence or effect on the percentage of perennial grasses along the gradient. There does not seem to be overgrazing of the areas given the dominance of perennial grasses. However, it was shown above in first paragraph of this section that the percentage of palatable grasses as compared to plots 600-1700 m and 1800 m was decreased.

4.3.2 Structure

The distance to perennial grass indicated no difference across all distance gradients. Percentage basal cover decreased with increasing distance from settlements. This can be attributed to difference in grazing intensity, with areas closer to the villages being more grazed frequently than areas furthest from the village. Grazing can cause loss of vegetation cover as a result of overgrazing resulting in decreased forage for livestock (Macharia & Ekaya, 2005). The results of this study therefore supports the hypothesis that there is lower basal cover in areas that are closer to the villages than areas further from the villages in the communal landscape. Kirkman (2002) highlighted that different animals can have different effect on grass tuft, in particular with sheep tending to graze selectively and closer to the ground and thereby negatively affecting the tillers

and reducing their ability to survive which is different to cattle. The negative effect that grazing can have on grass tufts has also been reported by Johnson (1956), where in high intensity grazing by cattle, there was realization of greater number of grass tuft but were small, weak and confined to the perimeter of the crown while on lightly grazed areas, grass tufts were originally larger but distributed uniformly over the plant crown.

4.4 Combined effect of rainfall, topographical and disturbance gradients on the herbaceous composition and structure

4.4.1 Composition

The composition, occurrence and spatial distribution of grass species were found to be associated with influence of different environmental gradients (Figure 14). The biotic and abiotic factors have a constraining role in the distribution of plants (Pellissier *et al*., 2013). The impact of grazing on plant composition in communal rangelands has been reported in literature including by O'Connor (2005), who reported in his study that grazing affected species composition. The study by Moesland *et al.* (2013), also found the species composition was linked to topographic variations and degree of moisture variations. Various other studies were undertaken by Maestre (2004) regarding other population variables and found that variation in species richness can be explained by environmental factors like elevation which showed positive relationship with species richness.

4.4.2 Structure

Consistent with the hypothesis there was significant interactive effect of rainfall, topographical gradients and distance gradient on the distance to perennial grass (Table 6). The effect of distance on perennial grass assumes high vegetation cover due to high rainfall, downslope position and less disturbance. The downslope positions have adequate resources for vegetation growth and are characterized by their high resources availability due to movement of water and nutrients from the upslope positions. Both abiotic and biotic factors were found to play a role on the structure of vegetation, such factors include, competition for resources, nutrient availability, precipitation patterns and disturbance factors (Jones *et al*., 2016). The structure of vegetation is due to adaptions to the environment by biotic components and their influences on the abiotic components (Sala & Maestre, 1988).

When determining the interactive effect on basal cover due to a combination effect of rainfall, catenal position and distance gradient it was found to be insignificant. This was contrary to the finding relating to distance to perennial grass as discussed above. Given that the p-value (0.08) of

basal cover variable was not far from the significant value it is speculated that with large sample size this could have be found to be significant.

Though the interactive effect of rainfall, topographical gradients and distance gradient on the distance to perennial grass has been confirmed in this study the impact of human activities can be shielded by other factors such as topographical variability, soil and vegetation types and land use. It has been further discussed in this study that bottomlands mostly have high moisture content that then becomes conducive to vegetation growth. Similarly, increased moisture availability has positive effect on vegetation growth as a result of mobilization of nutrient to downslope areas.
In conclusion, it was established in this study that overall rainfall zones had stronger effect on the herbaceous vegetation composition and structure when compared to catenal positions. Disturbance gradients had an effect on structure and composition of herbaceous vegetation, specifically on species richness and grass basal cover only, while there was no effect on Simpson's Diversity Index, perennial grass percentage, and distance to perennial grass. It was also established that there was association of species with environmental gradients.

5 CONCLUSION

It was the aim of this study to determine the influence that rainfall, topographical position and distance from village had on composition and structure of herbaceous vegetation in a communal rangeland. The determination was done both individually and based on their interaction. In determining this, firstly it was determined that only that species richness and Simpson's Diversity Index increased with increasing mean annual rainfall. The response of perennial grass percentage, distance and grass basal cover was contrary to what was hypothesized. Secondly, it was determined that no influence of catenal positions was evident on the composition and structures measures of herbaceous vegetation. Thirdly, it was determined that disturbance gradient had an effect on the composition and structure only on the species richness and grass basal cover measures. Fourthly, it was determined there was vegetation-environmental gradients relationship on occurrence of grass species and that interactive effect of rainfall, catenal position had effect on grass basal cover.

Based on the above, it is recommended that future search be considered in a multi-year study on the same variables that have been studied to reveal any long-term trends. This will serve to increase knowledge base in further understanding the influence of environmental gradients on the herbaceous composition and structure. This will be particularly useful in South African context given that there has not been enough similar studies done compared to on woody vegetation. It is further recommended that with regard to distance gradient sampling, greater consideration be placed on representativity of disturbance gradients samples to ensure that equal samples are taken for all gradients. Other factors like woody vegetation have been mentioned in the literature as having an influence on the herbaceous vegetation composition. It will be imperative as well to include this aspect of influence in future studies. It will also be beneficial to establish the density per village or stocking rates of different villages and the management of the stock where feasible and how it is related to herbaceous composition and structure.

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Map showing the study site within South Africa (source Available from:http://www.agincourt.co.za/index.php/about/maps/).[accessed 02 September 2014]

7 APPENDIX

Appendix 1 Key to species abbreviations used in CCA diagrams for herbaceous vegetation . the first three letters in an abbreviation refers to the genus name and second three letters refers to the species name**.**

Species Abbreviation	Full Species Names	Life Form
Aricon	*Aristida congesta*	Annual
Botins	*Bothriochloa insculpta*	Perennial
cyndac	*Cynodon dactylon*	Perennial
Digeri	*Digitaria eriantha*	Perennial
eragum	*Eragrostis gummiflua*	Perennial
Erarig	*Eragrostis rigidior*	Perennial
erasup	*Eragrostis superba*	Perennial
hetcon	*Heteropogon contortis*	Perennial
hypdis	*Hyperthelia dissoluta*	Perennial
Hypfil	*Hyperrhenia filipendula*	Perennial
panmax	*Panicum maximum*	Perennial
perpat	*Perotis patens*	Annual or short-lived perennial grass
pogsqu	*Pogonarthria squarrosa*	Perennial
setsph	*Sataria sphacelata*	Perennial
setspp	*Setaria species*	
Thetri	*Themeda triandra*	Perennial
Trigra	*Trichneura grandiglumis*	Perennial
trimon	*Tricholaena monachne*	Perennial
uromos	*Urochloa mossambicensis*	perennial
Aristi	*Aristida stipitata*	Perennial (shortlived)
ariads	*Aristida adscensionis*	Annual
braser	*Brachiaria serrata*	Perennial
branig	*Brachiaria nigropedata*	Perennial
bradef	*Brachiaria deflexa*	annual
dihamp	*Diheteropogon amplectens*	Perennial tufted grass
enncen	*Enneapogon cenchroides*	Annual
elimut	*Elionorus muticus*	Perennial grass-Tufted
erabic	*Eragrostis bicolor*	Perennial
eracil	*Eragrostis ciliaris*	Annual grass
eraleh	*Eragrostis lehmanniana*	Perennial
erahet	*Eragrostis heteromera*	Perennial. Tufted.
Eratri	*Eragrostis trichophora*	Perennial. Tufted.
eraspp	*Eragrostis unknown species*	
eramit	*Unknown Species*	
micafr	*Michorcloa caffra*	Perennial
melrep	*Melinis repens*	Perennial
orgeri	*Digeri? Digitaria ethiantha?*	Perennial
schsan	*Schizachyrium sanguineum*	Perennial.

Species Abbreviation	Full Species Names	Life Form
schpap	*Schmidtia pappophoroides*	Perennial
sponit	*Sporobolus nitens*	Perennial
cyndac	*Cynodon dactylon*	
Traber	*Tragus berteronianus*	annual
Stihir	*Stipagrostis hirtigluma*	Perennial/annual
spogun	*Unknown*	
spoafr	*Sporobolus africanus*	Perennial.
spopyr	*Sporobolus pyramidalis*	Perennial.
Setver	*Setaria verticillata*	Annual